The extinction of the rudist bivalves

Thesis

The extinction of the rudist bivalves

by

Nicola Helga Margaret Swinburne

M.A. Hons. (Cantab.) 1989

A thesis submitted for the degree of Doctor of Philosophy

August 1990

Department of Earth Sciences,

Open University

EX12

HIGHER DEGREES OFFICE

LIBRARY AUTHORISATION FORM

STUDENT: N.H.M. Swinburne SERIAL NO:

DEGREE: PhD

TITLE OF THESIS: The extinction of the rudist bivalves

I confirm that I am willing that my thesis be made available to readers and maybe photocopied, subject to the discretion of the Librarian.

SIGNED: NHM Swinburne DATE: 10th Oct. 1990

Acknowledgements

My general thanks go to Peter Skelton who supervised this project.

I should also like to thank José-Maria Pons and Enric Vicens of Barcelona for showing me the Pyrenean rudists and for invaluable guidance in the early stages; Angel Pamouktchiev for showing me the Bulgarian rudists (and much of Bulgaria as well); Camilla Pirini-Radrizzani of Genoa for advice on the Italian fieldwork; Ludmilla Šribar and Mario Pleničar of Ljubliana for helping in the collection of the Slovenian samples; Jim Kennedy of Oxford for some extremely useful conversations on aspects of the biostratigraphy.

The Sr-isotope work has been carried out at the Open University with the help of Peter van Calsteren who was responsible for running the samples on the mass spectrometer once they were loaded on filaments. This work could not have been realised without the help and encouragment of several other members of the department at the Open University. I would also particularly like to thank Mabs Kunka for her practical help and encouragement and Chris Hawkesworth for several useful discussions. Samples for Sr-isotope work from northern Europe were kindly provided by Jake Hancock of Imperial College, London and Wolfgang Weitschat of Hamburg and the modern bivalves by Liz Harper of the Open University. I should also like to thank Craig Smalley of B.P. for reading a draft of this chapter.

The work on the M. Jouf sequence is published in a co-authored paper with Adriano Noacco then of the University of Trieste and a copy of this paper (submitted to the Journal of the Geological Society of London) is available in the appendix. Adriano's contribution to this work is the map and section. The rest of the work, which is mine alone, comprises the detailed sedimentary logging of the limestone sequence and correlation of localities.

The Bulgarian work is to be published shortly in a joint paper with Michel Bilotte of Toulouse. We both visited the localities independently but the work presented in the thesis is essentially my account of this. Bilotte is responsible for identification of the foraminifera both from Bulgaria and from M. Jouf.

Abstract

The rudist bivalves were one of the many and varied groups of organisms to be extinguished at the end of the Cretaceous Period. They were a group of bivalves which evolved during Late Jurassic times to dominate the carbonate shelves on the margins of the Tethys Ocean during the Cretaceous Period. Through Late Cretaceous times their diversity climbed to a peak and then entered a period of rapid decline, resulting eventually in the complete extinction of the group.

Theories as to the cause of that extinction should clearly be based upon a knowledge of the detailed pattern of the decline. Most important is the question of the timing of the extinction: How long did it take from the peak of diversity to the elimination of the entire group? Is there one main extinction event - or are there several - or is the pattern a gradual decline? In answering these questions this work adopts a new approach to dating end Cretaceous strata by using strontium isotope stratigraphy. The method works by measuring the $^{87}Sr/^{86}Sr$ of palaeo-seawater preserved in marine carbonate, such as the thick low-Mg calcite layer of rudist shells. The $^{87}Sr/^{86}Sr$ of seawater was changing fairly rapidly through time in the latest Cretaceous. The pattern of change has been established in detail using samples from Boreal sequences of which the ages are known with respect to the belemnite stratigraphy. Using this as a standard graph, Tethyan rudist samples have been dated by a comparison of the Sr isotope ratio.

The use of Sr isotope stratigraphy has enabled a time axis to be established, against which the ranges of rudist bivalves and of their facies have been plotted. From these data it can be clearly seen that the ranges of many of the established biostratigraphic markers are in error and that the stage boundaries, as defined by the belemnite and planktonic foraminiferal stratigraphies, are offset.

When the pattern of rudist diversity is plotted against this time scale it can be seen that, at a specific level, the rudists were at their most diverse at the Campanian/Maastrichtian boundary. Their decline lasted until almost the end of the Maastrichtian after which the only survivors are Tertiary forms. The decline is related to the disappearance of rudist facies with the end Cretaceous regression, though that graph is slightly displaced from that of rudist diversity. This shows that the rudist extinction is not merely due to non-exposure of terminal Maastrichtian strata.

Table of contents

Figures

(N.B. The figures are not numbered and instead the number of the preceeding page of text is given.)

Chapter 1

Chapter 2

Chapter 3

Tables form part of text and are listed in table of contents.

Chapter 4

Chapter 5

Chapter 6

Appendix I

Appendix II

copy of Swinburne & Noacco, submitted to Journal of the Geological Society of London

---

Chapter 1: Introduction

1.1 The Tethys Ocean in the Cretaceous and the distribution of rudist bivalves

The rudist bivalves are a predominantly Tethyan group, that is they lived on the sides of the ocean which, in Mesozoic times, separated the northern continents of northern Europe and North America (Eurasia) from the southern continents of Africa, India and South America (Gondwanaland - see fig. 1/1 taken from Philip, 1982). Today the deposits from the margins of the Tethys ocean are found around the Mediterranean, in North Africa, the Middle East, Arabia, the Himalayas, East Indies and the Caribbean. Tethys is thought to have occupied an equatorial position in Cretaceous times and it is generally supposed that climate exerted the controlling factor upon the Tethyan distribution of the rudists. Rarely they are also found outside this range in southern areas such as Madagascar, Indonesia, Peru and northern areas such as Canada, Holland and Sweden (stars on fig. 1/1, see references in Philip, 1982).

The Tethys of the Cretaceous Period resulted from an earlier split of the supercontinent of Pangaea in Triassic times. This created the passive margin basin and horst topography which typified the southern margin, creating many of the platforms colonised by rudists in the Cretaceous Period. In the middle of the Cretaceous the continents began to split apart along another axis, that of the Atlantic, which had two main consequences for the rudists. Firstly, the Caribbean became isolated from European-African-Asian Tethys and from the Albian onwards there is a constant rise in the number of species and genera endemic to the Caribbean (Philip, 1982). (Some authors have given separate names to describe the separate, American part of Tethys, but I will use Tethys *sensu lato* to mean the circum-global equatorial ocean.) Furthermore, the scissor-like opening of the Atlantic, which began at different times in different places, caused Africa and India to move once more towards northern Europe and Tethys began to close.

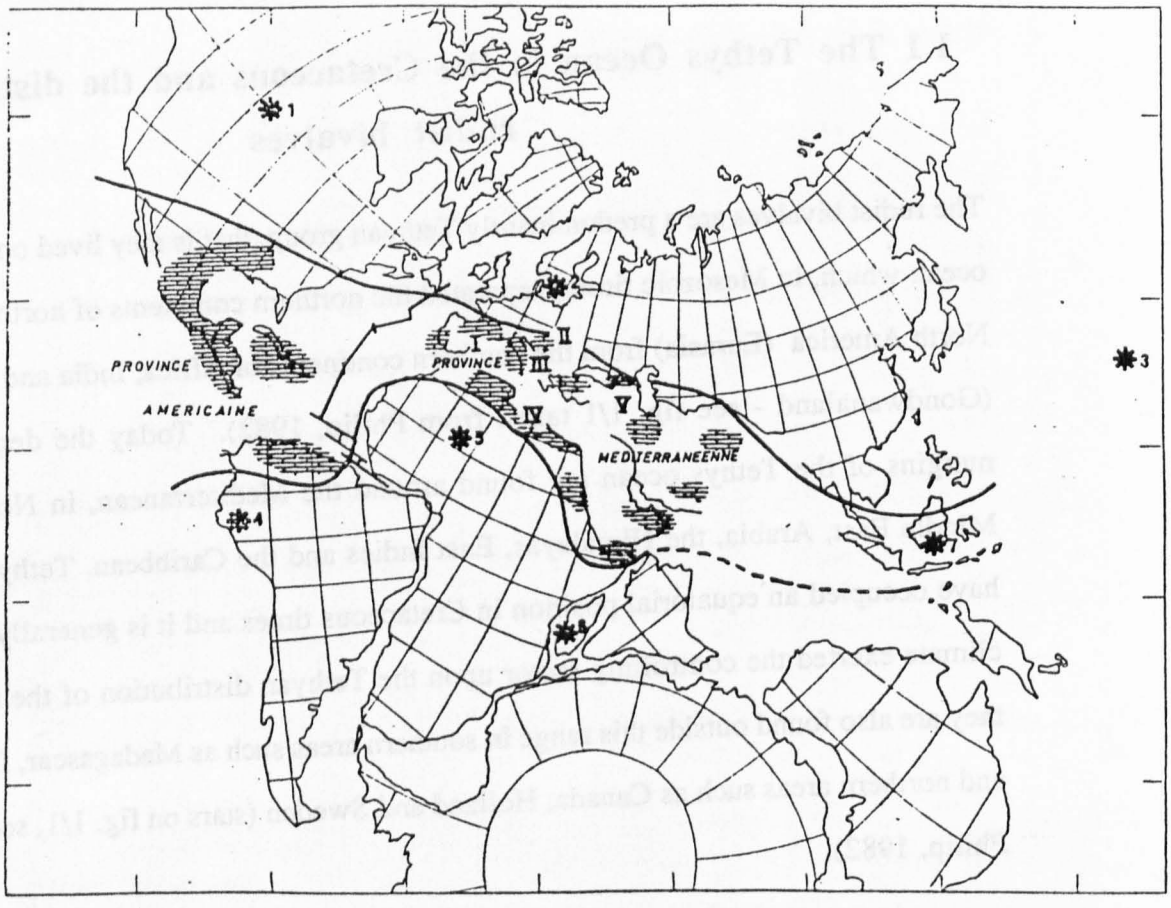


Figure 1/1. Palaeogeographic map showing position of the Tethyan Ocean in the middle of the Cretaceous. Stars indicate the finds of rudists in temperate regions which lay to the north and south: 1. Saskachewan; 2. Scandanavia; 3. Darwin seamount; 4. Peru; 5. Tademait Hamada, Algeria; 6. Madagascar; 7. Borneo. From Philip, 1982.

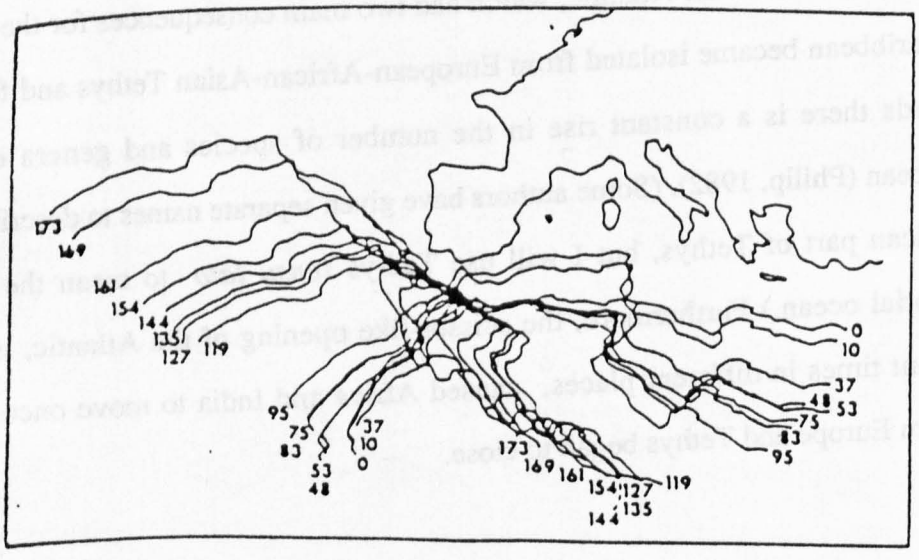


Figure 1/2. Motion of Africa relative to Europe. The successive positions of parts of the African coastline are shown relative to Europe. The numbers are ages in m.y.. From Livermore & Smith, 1985.

Using the palaeomagnetic spreading data from the two sides of the Atlantic the relative positions of northern Europe and Africa can be clearly charted (see figure 1/2 taken form Livermore & Smith, 1985). Yet the distribution of the smaller blocks which lay between the major blocks is far from clear. We know that the main line of junction of the two supercontinents runs through the Alps, east through the Inner Dinarides of Yugoslavia, the Taurus Mountains of Turkey, the Zagros Mountains of Iran and then the Himalayas (see figures 2/1 and 2/25). Westwards it can be drawn roughly between the Iberian Continent, which was part of the northern margin, and Africa itself which lay to the south. This leaves areas such as Italy, western Yugoslavia and Sicily, which are all technically parts of the African margin, in very uncertain positions. On a finer scale there is even more uncertainty over the distribution of different terrains as Alpine building caused so much shortening, crushing and over-thrusting that areas may be preserved far from their original position. To conclude therefore, with the exception of the isolation of the Caribbean, tectonic and palaeomagnetic information can not be used unambiguously to reconstruct the palaeobiogeographic provinces of the rudists. Indeed the palaeobiogeographic information may be just as useful to tectonicians in such reconstructions.

The palaeobiogeography may have influenced the rudist distribution but another important factor is the different ecological sites available for colonisation. The rudist bivalves were not framework-building organisms and did not, in general, build true reefs (Gili *et al.*, 1990). Instead, accumulations of rudists trapped sediment between them and built mounds. Early cementation of this sediment ensured that the mounds were fairly resistant structures, though not in the same way as modern coral reefs. Broadly speaking though, the areas which the rudists colonised are comparable with those of today's corals. Thus rudists lived on the passive margins of cratons (such as in the Pyreneen area or around the Arabian craton), on oceanic platforms which were horst blocks isolated during the previous expansion of Tethys (Periadriatic platforms). They also lived in volcanic areas which encompassed isolated atolls (parts of eastern Sicily) and on island arcs above subduction zones (Internal Dinarides and parts of the Caribbean). The advance or retreat of these areas of carbonate sedimentaion was

controlled by several factors: tectonic (such as major block movements and local faulting), global sea-level change and climate.

Whatever the cause, rudists do undoubtedly show some provincialism in Tethys. All authors would agree that the Caribbean shows a progressive tendency to endemism from the middle Cretaceous onwards. Philip, 1982, 1985b also stresses the internal divisions of European-African-Asian Tethys. For him these provinces are related to the distribution of the main plates and caused by the presence of physical barriers to the dispersal of forms. Philip, 1982 distinguished five areas several of which were reduced to subprovinces grouped into together in the central-eastern Mediterranean province in Philip, 1985b (see fig. 1/3). This later work also distinguished a new province at the same rank, the southern Iberian Province, separated from both the central Mediterranean and the Aquitano-Pyreneen province.

1.2 Diversity of the rudists through time

The following figures are taken from various recent papers of the last few decades showing how different authors have understood the changes in rudist diversity during the Late Cretaceous. Figure 1/4i by Coogan from the Treatise (Dechaseux *et al*, 1969) shows the standing diversity, presumably at generic level, for each family, through time as measured using stages of equal length. Figure 1/4ii uses data from the catalogue of hippuritid and radiolitid species in Sanchez, 1981 as presented graphically by Philip, 1982. It shows the number of new species appearing per stage. Figure 1/4iii from Masse & Philip, 1986 shows the total diversity in the solid line and number of new appearances in the dotted line, both at generic level.

The graphs show a general increase in rudist diversity though the Late Cretaceous. i) & iii) show a generally increasing standing diversity & ii) shows how this rate of production of new species is accelerating - which is to be expected if the per taxon diversification rate is constant. i) & iii) also show a temporary decrease in diversity at the Cenomanian/Turonian boundary and that much of this is attributed to extinctions in the Caprinids/Caprotinids/Monopleurids (not shown on figure 1/4ii). Incidently the anomalously

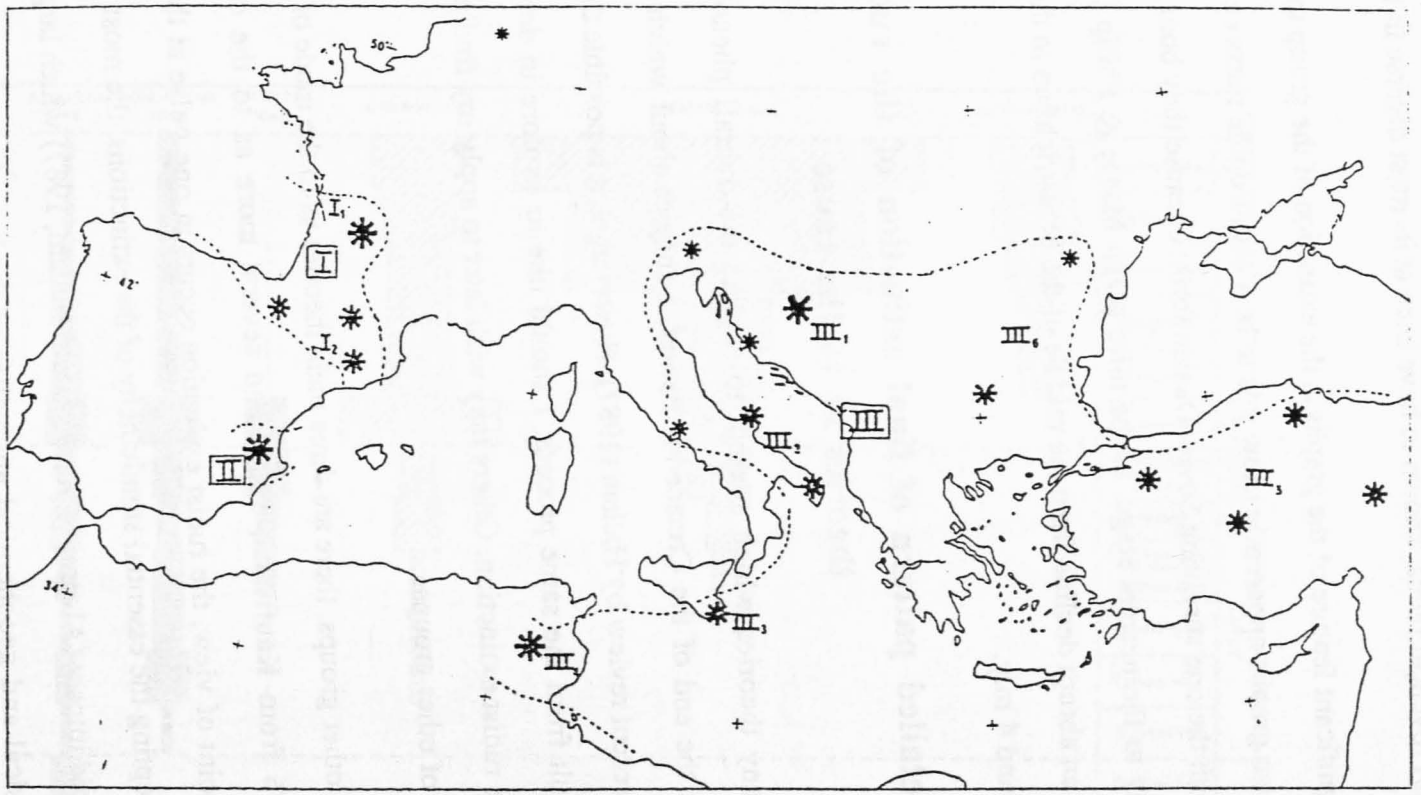


Figure 1/3. Distribution of Campanian - Maastrichtian rudist-bearing strata in the Mediterranean region: I Aquitane (I.1) and Pyrenees (I.2); II Southern Iberia; Central and Eastern Mediterranean (6 subdivisions) - III.1 North Adriatic. III.2 Apulia, Apennines. III.3 Sicily. III.4 Tunisia. III.5 Turkey. III.6 Bulgaria, Romania. From Philip, 1985

high diversity in Santonian times shown by Sanchez is probably due to an over-emphasis on the Pyrenean/Provençal fauna, known to have been at its most diverse in that stage.

The most significant feature of the graphs is the extinction of the group in the Maastrichtian. The earlier two graphs apparently show this to be a catastrophic mass extinction at the K/T boundary (with the one surviving Soviet Danian form) because they both use data where the dating is only to the nearest stage. In the third graph Masse & Philip (1986) portray the extinction as an abrupt decline from the middle of the Maastrichtian to the K/T boundary, a period of around 4 m.y.

1.3 Detailed pattern of final extinction of the rudists and theories as to the cause

There are many theories which attempt to explain the overall phenomenon of "mass extinction" at the end of the Cretaceous Period, a subject about which the the reader is refered to the recent review by Hallam (1987). However, as it is possible that the extinctions do not all result from the same process, I should like to explore in detail only the data concerning the rudist extinction. Others may wish later to apply my findings to explain the disappearance of other groups.

As with all the other groups, there are three main theories as to the mode of rudist extinction (see figure 1/5 from Kauffman, 1988) and several more as to the cause. From the catastrophist point of view, the rudist extinction occurs in one pulse at the K/T boundary (fig. 1/5i). Accepting the essential simultaneity of the extinctions, the most popular cause is that of an asteroid impact (Alvarez *et al.*, 1980, cit. Hallam, 1987) which largely explains the numerous physical and geochemical anomalies of the boundary clay (iridium anomaly, shock quartz, glass spherules, soot, etc.). Any apparent decline in rudist diversity prior to the boundary would be explained as a consequence of non-exposure of terminal Cretaceous strata.

A modification to this theory, still promoting an extinsic mechanism for the extinctions is that of Hut *et al.* (1987). They accept that some extinctions took place before the K/T

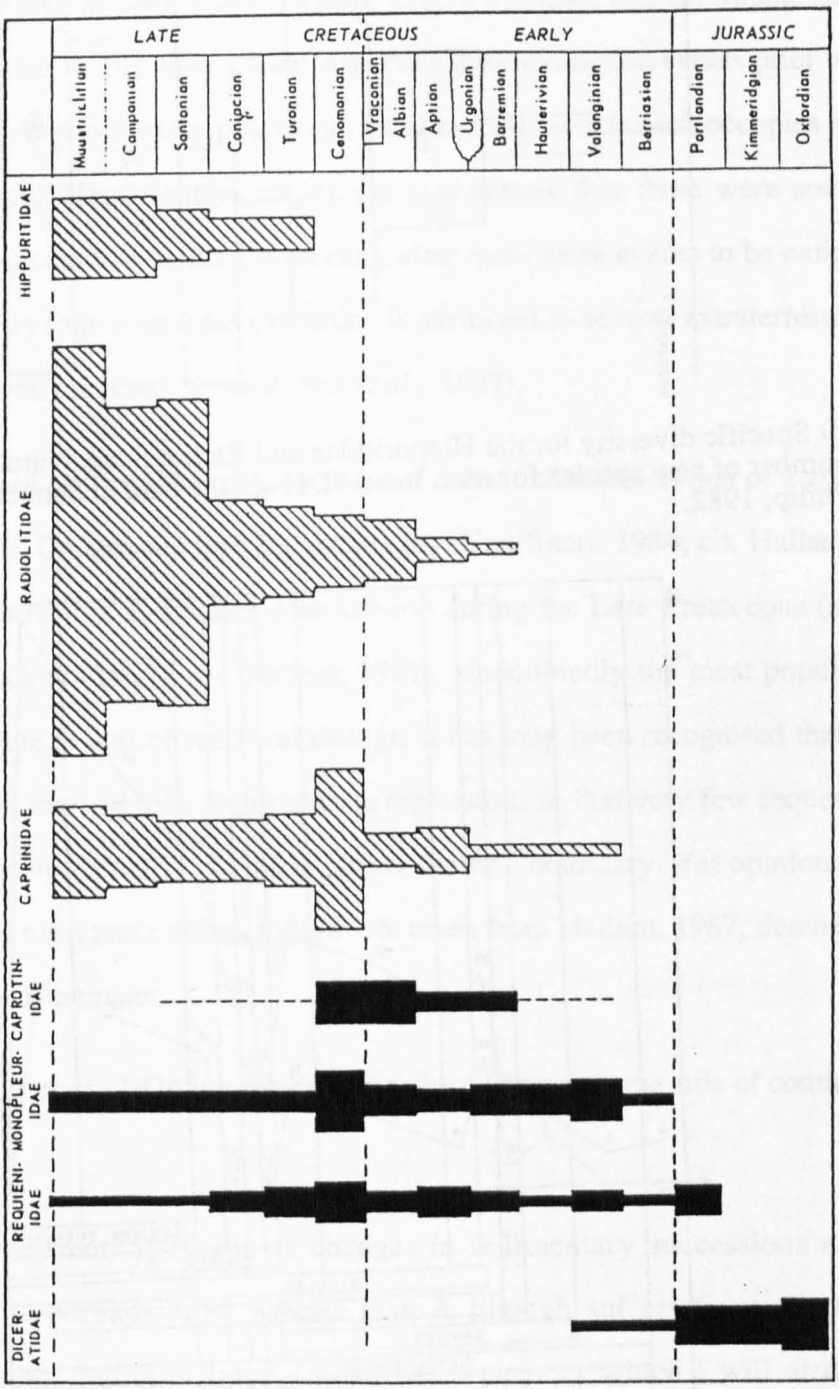
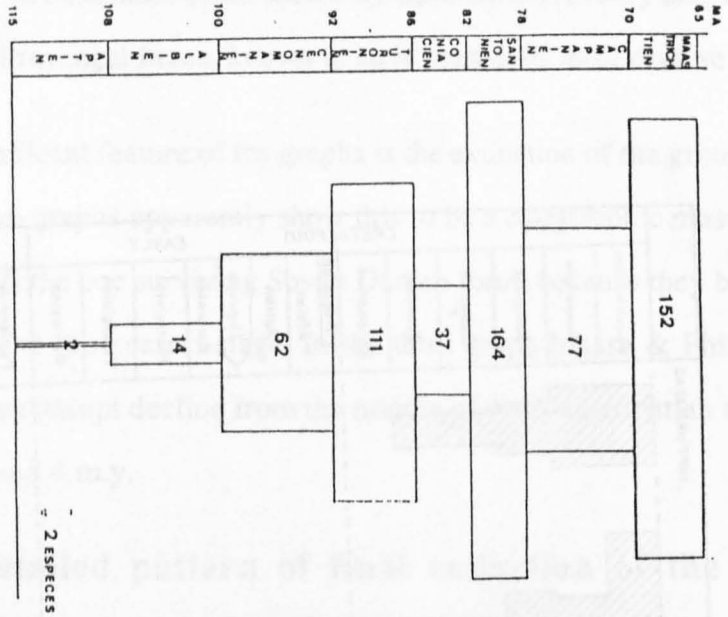
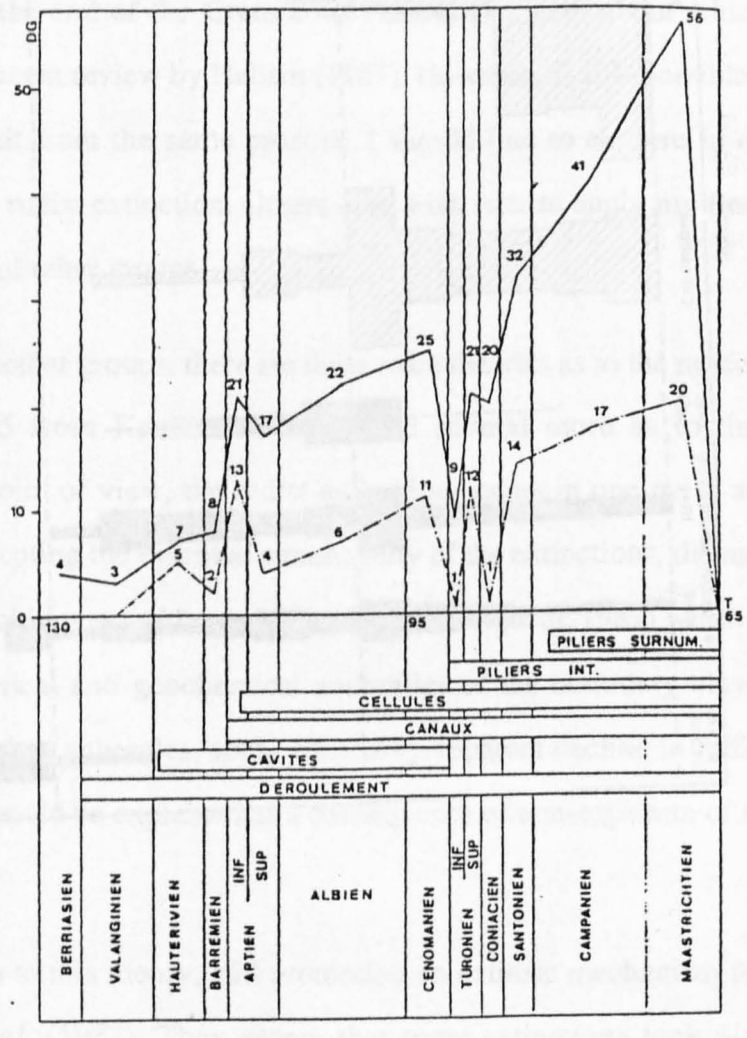


Figure 1/4. Rudist diversity against time for the Late Cretaceous.
i) Generic diversity for the various rudist families from Coogan in the Treatise

Figure 1/4 cont.



ii) Specific diversity for the Hippuritidae and Radiolitidae. Numbers indicate the number of new species for each interval. From the data in Sancehz, 1981, plotted in Philip, 1982.



iii) Generic diversity against time in m.y.. Continuous line shows the total number of genera for each stage or substage, discontinuous line shows the number of new generic appearances. From Masse & Philip, 1986.

boundary, but that the extinctions occurred in distinct pulses (figure 1/5ii). Data for the rudist extinction which seemingly conforms to this pattern is provided in that work by Kauffman (Kauffman & Johnson, cit. Hut *et al.*, 1987 as "in press") based on work in the Caribbean (though he also claims the same pattern for Spain and the Middle East - the former at least is refuted in this work). Kauffman cites three extinction events prior to the boundary all within the *A. mayorensis* planktonic foraminiferal zone (which occupies perhaps the last 2-3 m.y. of the Maastrichtian stage). He also claims that there were some rudists left, (though not necessarily in the Caribbean), after these three events to be extinguished at the boundary. This step-wise mass extinction is attributed to several extraterrestrial impacts, all part of the same cometary shower (Hut *et al.*, 1987).

Another school of thought sees the pattern of rudist extinction as that of a gradual decline at the end of the Cretaceous (see fig. 1/5iii) (eg. Kauffman, 1984, cit. Hallam, 1987). Some see the cause of this as climate deterioration during the Late Cretaceous (as shown in the plants by Hickey (1981), cit. Hallam, 1987). Undoubtedly the most popular reason for a gradual decline is that of sea-level change. It has long been recognised that the end of the Cretaceous is marked by a major marine regression, so that very few sequences of shallow marine facies are actually complete across the K/T boundary. Yet opinions on the precise timing of the regression differ. Figure 1/6, taken from Hallam, 1987, demonstrates three of the more recent estimates.

A) from Sliter *et al,* 1976 is a qualitative estimate based on the area of continent covered by sea.

B) from Kauffman, 1979 shows changes in sedimentary successions as well as areal changes. It is perhaps more precise than A (though suffers from all the problems of biostratigraphic dating of latest Cretaceous sequences which I will discuss in the next section).

C) from Haq *et al,* 1987 and is based on seismic stratigraphy. Several authors (eg Jones *et al.*, 1987) have doubted the implication of these authors that the sea-level minimum was not reached at, but before, the end of the Maastrichtian.

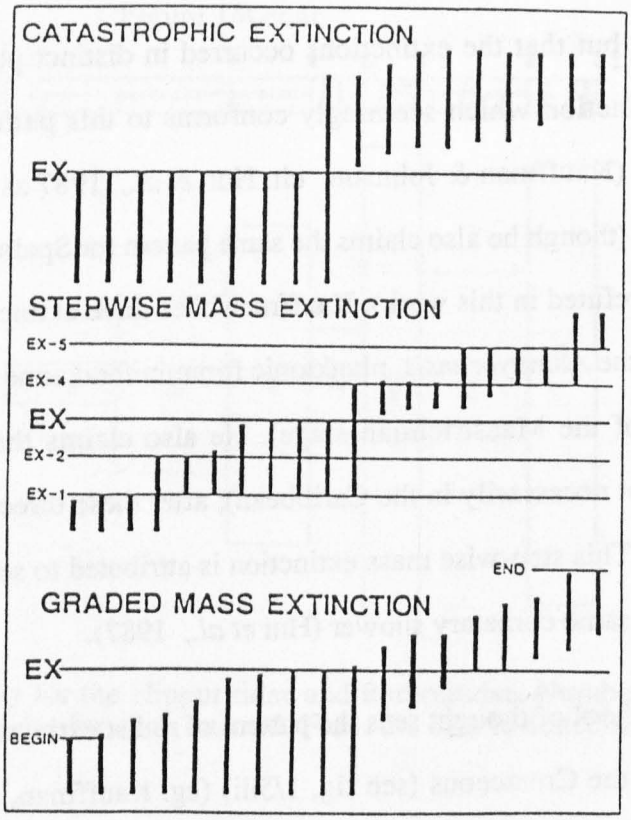


Figure 1/5. Models for three major mass extinction hypotheses.
i) Catastrophic; ii) Stepwise; iii) Graded mass extinction. From Kauffman, 1988

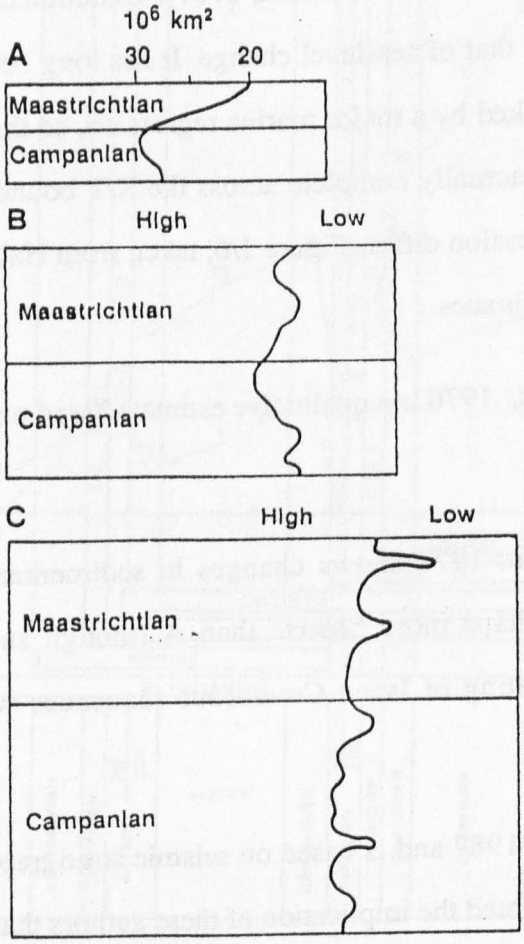


Figure 1/6. Three recent estimates for the timing of the end Cretaceous regression, taken from Hallam, 1987.
i) based on the area of continent covered by sea, from Sliter *et al.*, 1976
ii) based on changes in sedimentary successions as well as areal changes, from Kauffman, 1979
iii) based on seismic stratigraphy from Haq *et al.*, 1987.

1.4 An outline of the questions to be answered

Evidently the solution to the cause of the rudist extinction would be nearer if the mode of that extinction were better known. In this thesis I explore this problem and attempt to answer the following questions:

1. How long did it take from the peak of diversity to the extinction of the group? Is this decline gradual, stepwise or one abrupt event.

2. Why are the rudists at their most diverse at the end of the Cretaceous - is the increased diversity associated with increased endemism? If so what factors are responsible for the endemism?

3. Is the extinction related to a disappearance of facies - and therefore rudist habitat - caused by sea-level change. If so what is the exact relationship between these?

1.4.1 Dating the extinction of the rudists

The rudist deposits discussed in the foregoing chapters have up till now been dated using biostratigraphic methods. The beds are dated by the occurrence of indicator fossils which are known elsewhere to be of a certain age. They are known to be of that age either directly, because the age of that section was defined (ie. it is the type sequence), or indirectly via other fossils, eventually resulting in a correlation with a type sequence. The two main biostratigraphic indicators in sediments bearing rudist bivalves are the rudists themselves and benthic foraminifera, both organisms whose presence is highly dependent upon facies. The consequence of that is that the local range of a rudist or foraminiferal species coincides with the disappearance of the facies and is very much less than the total evolutionary range of the form. This gives a certain "random error" to the biostratigraphic dating which is not sufficiently emphasized, especially by specialists working on these groups of organisms. Dating of beds using rudists and benthic foraminifera generally cannot be more precise than stage level in my opinion.

There is also a "systematic error" in dating deposits from the latest Cretaceous. The end Cretaceous regression resulted in a change in sedimentation and produced the unconformity which now delineates strata from the two eras. Sediments of shallow water shelf facies representing the very end of the Cretaceous generally do not exist, yet the extent of this stratigraphic gap, or lacuna, of strata of latest Maastrichtian age has frequently been underestimated or ignored. Thus biostratigraphic markers present in the upper part of the Maastrichtian sequence wrongly gained reputations as late Maastrichtian zonal fossils (when in fact they were older). Biostratigraphy works on a copy-cat basis. If a piece of information further down the chain is wrong then this mistake is perpetuated throughout subsequent literature. Hence from the literature there seems to be more strata of purported late Maastrichtian age than is now thought to exist.

I therefore thought it necessary to use an independent method of dating these sequences, that of Sr isotope stratigraphy. This works on the principle that the ratio of $^{87}Sr/^{86}Sr$ of the worlds oceans at any one time is the same, but that through time it changes in a regular way. Once it is established how the ratio changes through time (as represented by the stratotype), then it is possible to go to an unknown area and date sequences by a comparison of the Sr isotope ratio. In the Campanian and Maastrichtian Sr isotopes offered the possibility of the relative dating of sequences to errors of the order of ±0.5-1 m.y which, given a Maastrichtian Stage of around 8 m.y., is highly desirable.

Dating using the Sr-isotope stratigraphy is a different approach because it does not consider ages in terms of zones, and (if the Sr isotope ratio changes linearly through time), the error on all dates should be the same. This is not the situation for biostratigraphic dating. For example using planktonic foraminifera to date Maastrichtian strata there would be a fine dividing line discriminating between strata of one zone or another. The dating system would then be used to date strata terms of perhaps 10,000's of years for beds which were deposited at a time of rapid foraminiferal speciation -that near zonal boundary (the lowest achievable error depending on the extent of diachroneity of a particular foraminiferal extinction or appearance). However for strata deposited in a time of low foraminiferal speciation, that

now representing the middle of a zone, the error would be more like ±1.5 m.y. It is this difficulty of dating of events within a zone which often results in the assumption that the entire zone is represented.

1.4.2 Rudist endemism at the end of the Cretaceous

Apparent endemism can be artificially created by authors studying different geographical areas and giving different names to what is the same form. It can be as much a facet of human isolation - due to different methodologies of groups of workers and lack of exchange of literature - than of rudist palaeobiogeography. The extent of difference of forms from the various regions must therefore be assessed.

1.4.3 Facies changes in the rudist sequences

It is quite likely that the increase in rudist diversity was due to the creation of a wider variety of environments which they were able to colonise and that their extinction was caused by a loss of this habitat. I will therefore try to establish what kind of environment is represented in the facies in each area, what kind of rudists tend to be associated with that facies, and whether the disappearances of the rudists are associated with a facies changes.

1.5 Extent of thesis and practical work contributing to it

The project began with the intention of studying the rudists of the Maastrichtian Stage but as I began to realise how much of these strata are actually Upper Campanian I had to widen the scope of the study to include most purported Upper Campanian strata as well. This ensured that I considered the problem of rudist extinction from just before the peak in diversity to their extinction at the end of the Maastrichtian. I was restricted in practical terms to work on the rudist fauna of Eurasian Tethys, the Caribbean being a separate biogeographic provnice in the Late Cretaceous. I have therefore not been able to assess the validity of Caribbean rudist species, nor to comment on the dating of the strata which uses other faunas (such as inoceramids or ammonites) either endemic to the New World, or at least unlikely to have the same biostratigraphic ranges. I therefore report on the conclusions of others as to the extinctions in the Caribbean province.

My own practical work for this project included studying one representative sequence of the oceanic carbonate platforms of Central Tethys, at M. Jouf, from the Adriatic Carbonate Platform in northern Italy. I logged the sequence, collected and determined the rudist fauna, photographed the benthic foraminifers and carried out detailed Sr-isotope work. I saw something of the local geology both of the M. Jouf area and also on a larger scale of the northern part of the Adriatic Platform so as to appreciate events in the latest Cretaceous - Early Tertiary interval.

I carried out less extensive field work in Bulgaria, looking at the sedimentology of the rudist localities and re-evaluating the rudist fauna from museum collections. I found several benthic foraminifers in thin sections of these sediments which I photographed and which were later identified. The identification of the foraminifers together with the Sr-isotope work lead to a redetermination of the age of the localities. The Bulgarian sequences were from the eastern part of the northern Tethyan margin and the limestones are closely associated with volcanics. They are very similar to sequences in nearby eastern Serbia from which one of the important biostratigraphic schemes for Maastrichtian rudists originates.

In Spain I studied the rudists from the Spanish Pyrenees. Many of these forms form the basis of Douvillé & Toucas' original classification system upon which most later work is based. I have also seen the collections at the Natural History Museum in London (BMNH) and at the O.U., which enabled me to appreciate some of the Arabian and Middle Eastern fauna.

I obtained samples for Sr-isotope work from the French and Spanish Pyrenees, from the Adriatic Platform in N. Italy, Slovenia and coastal Croatia and from the E. Serbia-Bulgarian platform in Bulgaria. These are areas with relatively well established stratigraphy and enabled me to assess the ranges of some of the better known biostratigraphic markers. I also constucted a standard graph of Sr-isotope change through time from samples from the Boreal Santonian-Maastrichtian.

1.6 Contents of thesis

The following points on the construction of the thesis are relevant to all the chapters. In order to cover sufficient information on the rudist deposits of the entire European-African-Asian part of Tethys I have made use of several papers which review the fauna of an area and have provided the authoritative opinion(s) on the age of that deposit. I have usually paraphrased the arguments presented in these papers and where I have interrupted the original authors' accounts with my own comments, I have done so in square brackets. Any references to original works mentioned in these papers, and where I have not checked the accuracy of that second-hand account, I have refered to the citation and not the original reference (and the original is not present in my bibliography).

The various separate strands to this thesis are set out in the next four chapters. Chapters 2, 3 & 5 describe most of the major Upper Campanian-Maastrichtian rudist localities of Tethys. The areas are divided into sections and subsections in a numbering system which attempts to follow the original palaeogeography.

Chapter 2 includes some details of the palaeogeography under each section but is mainly concerned with the sedimentology/lithostratigraphy of the deposits.

Chapter 3 presents tables of the known rudist occurrence as given in the literature. At the end of this chapter there is an attempt to assess the validity of the purported species and genera. This is only done at an informal level as a complete taxonomic revision of this large number of rudist species is a life-time's work in itself. It might be suggested that these remarks would only add to the confusion as they carry no taxonomic status and would be better omitted. Their vital significance however will become clear in the conclusions in chapter 6.

Chapter 4 is a presentation of the Sr-isotope work from the basic premises to the potential problems of the technique and misinterpretations of the data. The results are presented graphically and an age for the deposit concluded in this chapter. Tables of these results can be found in the appendix.

Chapter 5 is a presentation of the arguments used by the authors of the various studies for the dating of the rudist strata. In this I have reported the reasoning given by these authors for the age assignments so that when I had corrected some of the lines of evidence, I could then revise the final age. In the table accompanying each of the better known areas, and at the end of each section, I have given my own view as to the age of the each deposit.

The question of the mode and cause of the extinction of the rudists is addressed in chapter 6 which uses all the varied types of information from the foregoing chapters.

Chapter 2: Description of rudist sequences

2.0 Introduction

The rudist deposits are described under the following seven main regions which form sections of this chapter (numbered 2.1, 2.2 etc.).

1. Pyrenees
2. Periadriatic
3. North Africa
4. Balkans-Eastern Alps
5. Middle East
6. Arabia
7. Northern Europe
8. Caribbean

For the present day location of the rudist outcrops the reader is referred to figure 2/1 (Mediterranean area), and 2/25 (Middle East and Arabia). The numbering system for the regions and subregions broadly follow the palaeogeography, a subject alluded to in chapter 1 (see also figure 6/5 for a map of a reconstruction of the position of the main blocks). To recap, regions 1 & 4 and possibly parts of 5 are part of the northern margin of the Tethys Ocean. Regions 3, 6 and most of 5 formed the southern margin. Region 2 lay in an intermediate, oceanic position, although it was probably more closely connected to the southern margin. Region 7 describes the Boreal Ocean which could freely interchange waters with Tethys at many places across continental Europe. Region 8, the Caribbean was a separate part of the Tethys (*sl.*), isolated, as it is today, from the rest of Eurasia by the Atlantic to the east and the Pacific to the west. More detail on the palaeogeography of each region can be found in the introduction to each section.

2.1 Pyrenean Region: Pyrenees, Aquitaine, Sardinia

2.1.0 Introduction

Cretaceous shallow water sediments were laid down in a belt between the northern European landmass and the southern Iberian (or Ebro) continent. Most of these deposits are now

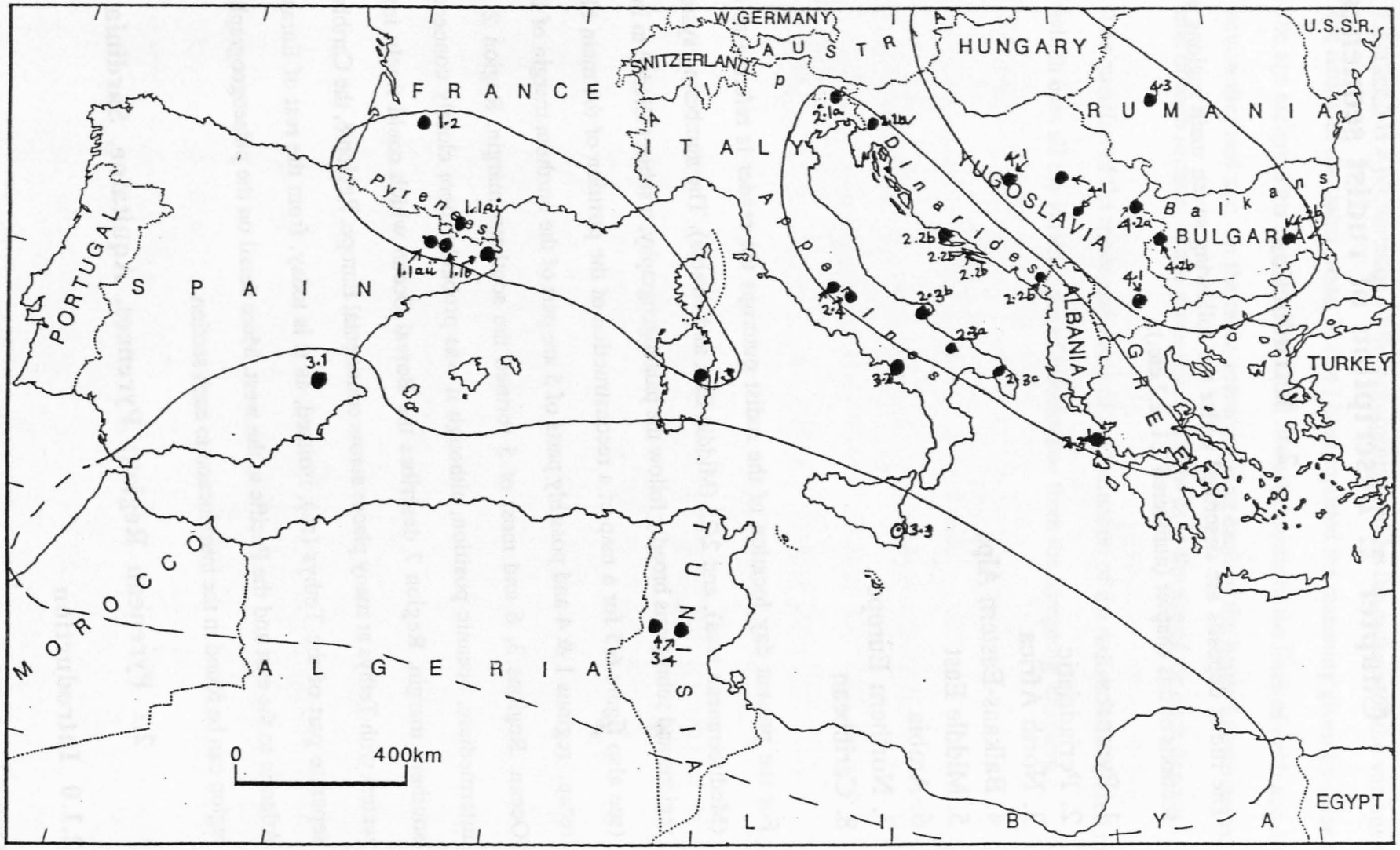


Figure 2/1. Map of the present day geography of the Mediterranean region showing the location of Campanian-Maastrichtian rudist strata. Localities are grouped into Palaeogeographic regions and numbered as in the text.

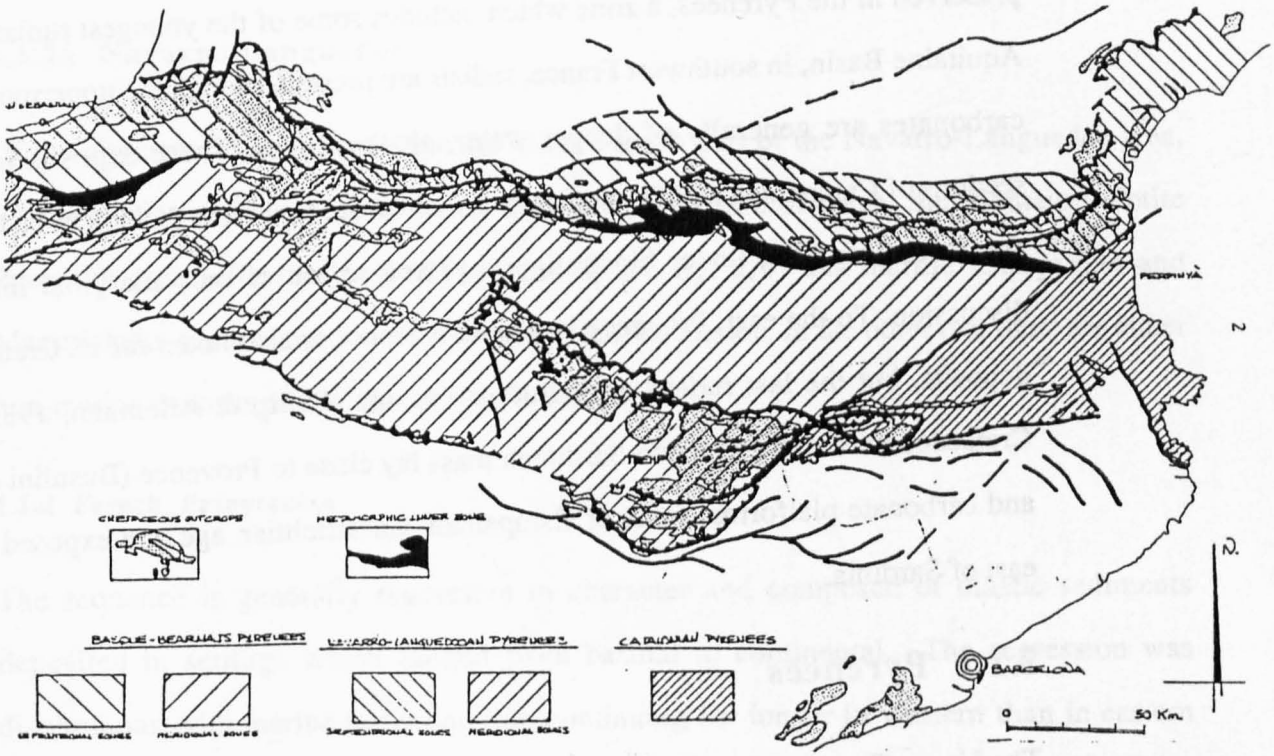


Figure 2/2. Map of the Pyrenees showing location of the main structural blocks redrawn from Souquet *et al.*, 1977.

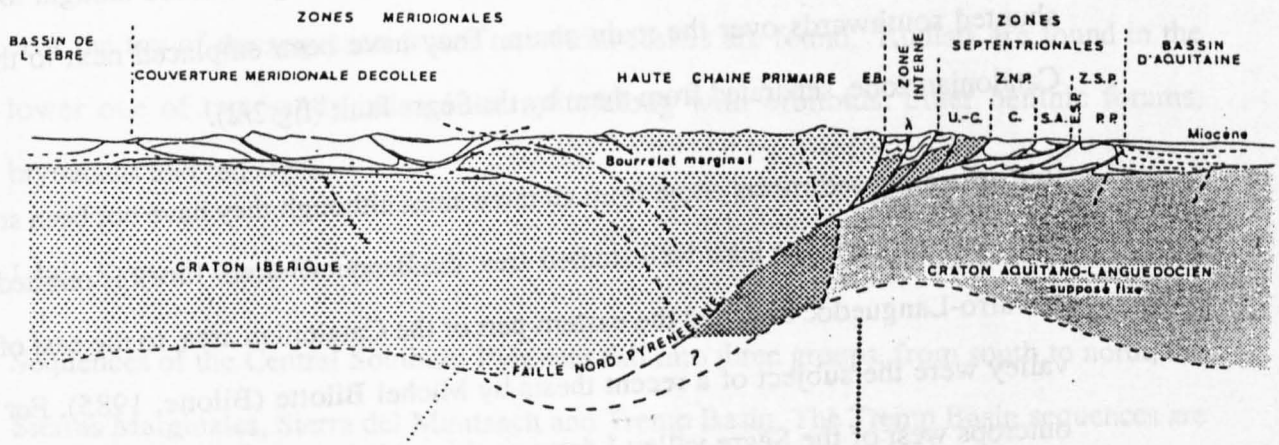


Figure 2/3. Section across the Navarro-Languedoc Pyrenees showing the unit known as the "couverture méridionale décollée", sediments originally deposited on the French side, but shunted southwards over the main Pyrenean chain. From Souquet *et al.*, 1977.

preserved in the Pyrenees, a zone which includes some of the youngest rudist strata. In the Aquitaine Basin, in southwest France, rudists are present, though the uppermost Cretaceous carbonates are generally of deeper water, chalky facies. These deposits form the type sections of Campanian and Dordonian strata which are both now thought to be Campanian in age (see discussion under biostratigraphy) and so are of only marginal interest to this discussion. To the east, Provence in southern France is also noted for its Cretaceous rudist deposits, but the last rudists are Santonian in age (Philip & Allemann, 1982). In Late Cretaceous times, the Corsico-Sardinian mass lay close to Provence (Busulini *et al.*, 1984) and carbonate platforms, some of Campanian-Maastrichtian age are exposed today in the east of Sardinia.

2.1.1 Pyrenees

The Upper Cretaceous rudist carbonates of the Pyrenean region are found in the foothills of the Pyrenees either side of an inner zone with Palaeozoic rocks. The Pyrenees divide conventionally into three sectors separated by major structural lineaments: the Basque-Bernais, Navarro-Languedoc and Catalonian Pyrenees (fig. 2/2). Of these three sectors, the Navarro-Languedoc and Basque-Bernais blocks have representatives of the deposits of both continents, whilst the Catalonian area includes only rocks and sediments derived from the Iberian continent. In particular sediments of the so-called "couverture meridionale décollée" (see fig. 2/3) were actually deposited on the northern margin but are thought to have been shunted southwards over the main chain. They have been emplaced next to those of the Catalonian zone, separated from them by the Sègre fault (fig.2/2).

Rudist-bearing sediments come from all three areas although they have not been studied with equal intensity and the least well studied area, the Basque-Bernais block is omitted here. The Navarro-Languedoc area and the eastern part of the Catalonian area, to the east of the Ségre valley were the subject of a recent thesis by Michel Bilotte (Bilotte, 1985). For the rudist outcrops west of the Sègre valley I draw on the published and unpublished accounts of the workers at the University of Barcelona at Bellaterra, notably José-Maria Pons and Enric Vicens.

2.1.1a Navarro-Languedoc

Of the uppermost Cretaceous deposits in the French part of the Navarro-Languedoc area, Bilotte distinguishes three subzones. However, only one of these, the Plantaurel-Petite Pyrenees area (effectively the Prepyrenees, see fig. 2/4) has marine Campanian and Maastrichtian sediments and so is relevant to this discussion. In the other two there are either non-marine deposits or else the interval is a lacuna.

1.1ai French Prepyrenees

The sequence is generally regressive in character and composed of clastic sediments deposited in settings which ranged from basinal to continental. The regression was diachronous with marine sedimentation continuing for longer in western than in eastern areas. Sediments of the western areas ("Plagne" and "Richou Montfa") are recorded in figure 2/5. The Lower Campanian strata consists of pelagic marls with some rudist limestones. In western areas similar sediments were still being deposited in Late Campanian and Early Maastrichtian times (*sensu* Bilotte) in a unit known as the Marnes de Plagne. This is overlain either by the Grès de Labarre, which mainly comprises shallow marine and fluviatile sandstones, or by sandy limestones with orbitoids of the Calcaire nankin, which is around 120m thick. Overlying these units in the west is around 250m of the Marnes d'Auzas. The beds are silty and lignitic marls with some sandy intercalations, particularly near the top of the sequence where terrestrial fossils are found. Rudists are found in the lower one of two sandy calcarenite units along with orbitoids, other benthic forams, bryozoans and red algae.

1.1aii Central Southern Pyrenees

Sequences of the Central Southern Pyrenees fall into three groups, from south to north, the Sierras Marginales, Sierra del Montsech and Tremp Basin. The Tremp Basin sequences are the thickest of all and were deposited in the deepest water, furthest from the Iberian continent. In contrast, the Sierras Marginales sequences are quite thinly developed and were

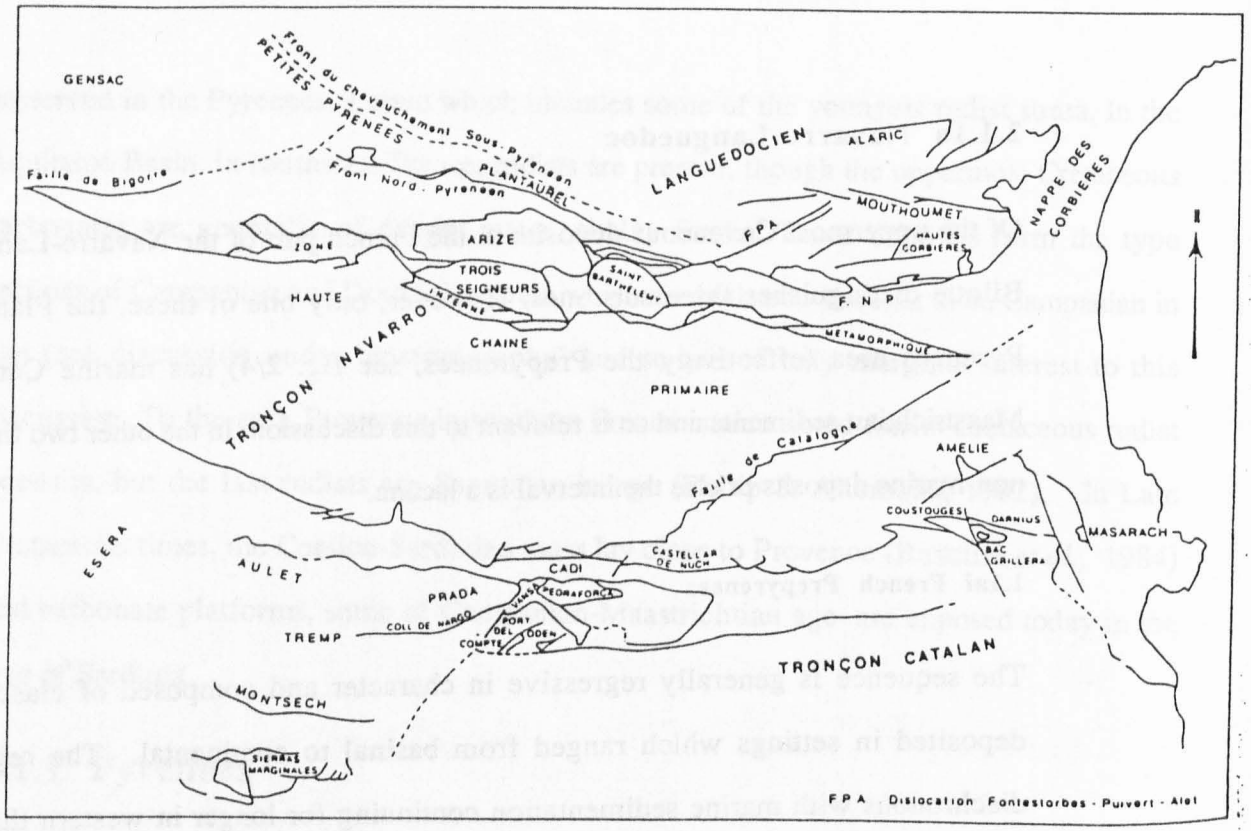


Figure 2/4. Detailed location map of the eastern Pyrenees. From Bilotte, 1985

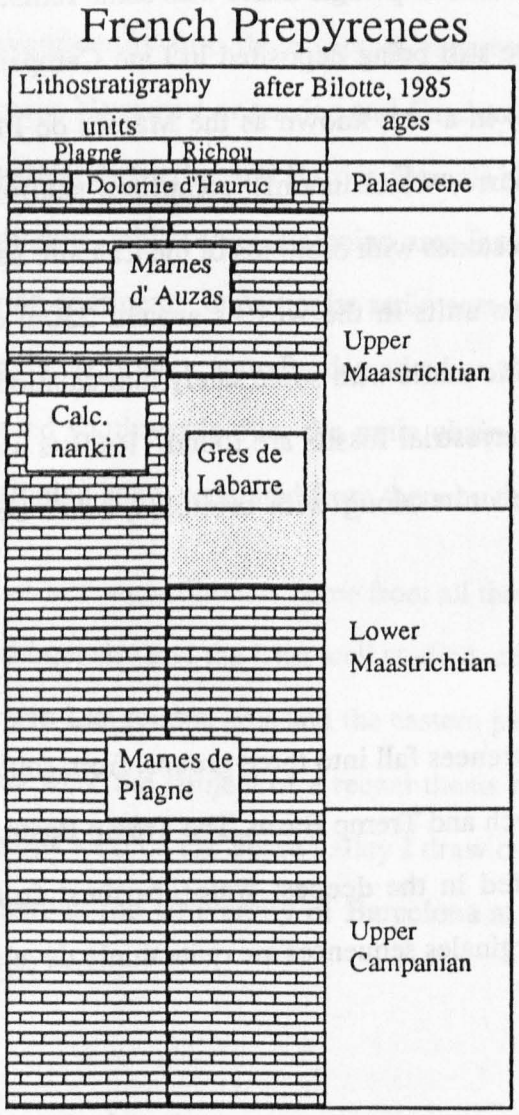


Figure 2/5

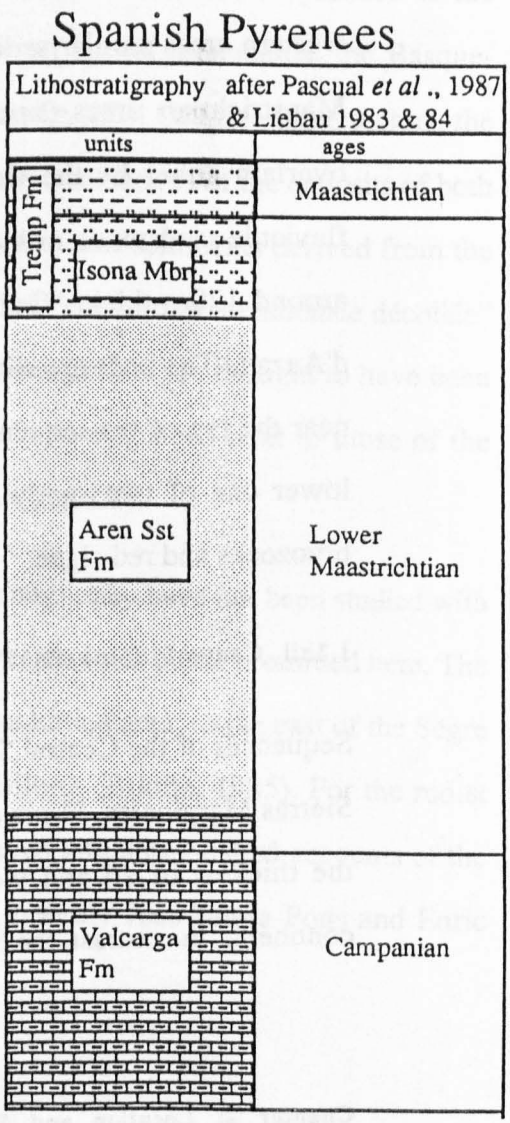


Figure 2/6

Figure 2/7. Map of Yugoslavia and surrounding countries showing distribution of Campanian- Maastrichtian outcrops.

laid down nearest to the shore. They are reliably correlated with the Montsech sequences and contain no additional faunal elements of biostratigraphic significance.

The following description of the Montsech deposits is based on the description of the Clot d'Olsi - Alçamora section from Pascual *et al.*, 1987 and the review of Caus *et al.*, 1981 which described the lower part of that section and the upper part of the adjacent Terradets section. The rudist samples analysed for Sr-isotopes came from the Clot d'Olsi - Alçamora section and were from the collections of Pons and Vicens. The Tremp basin stratigraphy is described by Gallemi *et al.* (1983). The uppermost unit of the sequence, the Tremp Formation as it outcrops at the top of the Montsech sequence, and at other localities in the Tremp anticline is documented in Liebau, 1983, 84.

In the Sierra del Montsech area the Mesozoic sediments actually overlie Cenozoic beds over which they have been thrust. In Late Cretaceous times marine sedimentation marked the start of a transgression over the area and the eventual establishment of a carbonate platform which showed its greatest development in Campanian times. Thereafter the deposition of terrigenous materials increased markedly and conditions changed gradually from marine to continental. Rudists, which were at their most diverse in the Santonian times are also found in abundance in Campanian and Maastrichtian strata.

The Upper Campanian part of the section (fig. 2/6) is the upper part of the Vallcarga Formation (alternatively known as the Calizas de Terradets). This consists of around 300m of grey-beige, fairly well-bedded, bioclastic limestones. Rudists are restricted to certain levels but the sediment generally includes benthic foraminifera, algae, bryozoa, echinoids, bivalves and rudist debris. Going upwards in the sequence the sand content increases until sandstones come to dominate limestones. This marks the base of the Aren Sandstone Formation (or Areny Sandstone Fm.) which is around 500m thick. The sandstones are brown, calcite-cemented, coarse-grained and frequently show large-scale cross bedding. Both formations are typical shallow-marine in character evolving from shallow neritic to littoral. The overlying beds of the Tremp Formation (known historically as the Garumnian facies) show a change to a predominantly continental facies. The beds are mostly grey clays

and brown micritic limestones with charophytes, ostracods and gastropods but in the lower 100m there are also some lagoonal marl beds which contain rudists.

The Vallcarga Formation in the Tremp Basin consists of deep water muddy turbidites. The subsequent Aren Sandstone Formation with sandstones, sandy marls and sandy, cross-bedded calcarenites represents an environment evolving from deep marine to neritic to littoral but which was still unsuitable for rudists. Only in the lagoonal intercalations at the base of the Tremp Formation (Isona Member) are rudist occurrences noteworthy.

2.1.1b Catalonia

Strictly speaking there are two zones to be included here: the Pedraforca area of the eastern Pyrenees to the east of the Sègre fault (Prov. Llerida & Barcelona); and the Alt Emporadà area near the Mediterranean coast (Prov. Girona). This discussion only includes the former as detailed accounts of the latter are still awaiting publication.

In the Pedraforca area, younger Mesozoic sediments of Campanian and Maastrichtian age overlie unconformably older rocks, which vary from Jurassic to Permian in age. The deposits are divided by Bilotte (1985) into units of autochthonous, parautochthonous and allochthonous origin. In the autochthonous and parautochthonous area the succession starts with an initial transgression bringing shallow marine sandstones and conglomerates. This is overlain by rudist-bearing limestones and sandy marls then by bryozoan limestone. Together these comprise the Bona formation (or Grès du Mas Gaou in one area). At the top of the sequences come micritic limestones with charophytes demonstrating a more fluvio-deltaic influence, and finally red clays of continental origin. The sequences are regarded as the lateral equivalent of those of the Sierras Marginales and the rudist beds partially equivalent to those of the Tremp Formation.

In the allochthonous unit of the Pedraforca Nappe both the Campanian and Maastrichtian stages are well represented. The sequences are much thicker (300-800m of marine beds) than in the autochthonous units and they are considered the lateral equivalent of the Montsech sequences. Rudists are found in the "Calizas de Terradets" or Vallcarga

Formation, sediments which are a mixture of limestone, sandstone and clay material and representative of inner platform environments. These are overlain by marginal marine-fluviatile facies of the Tremp formation.

2.1.2 Aquitaine

The chalk sequences in the Aquitaine Basin, in the south of France are also worth mentioning because of their historical interest. These beds include the type Campanian Stage and the Dordonian strata of Coquand, 1856 & 57 which is now thought to be Upper Campanian (see under introduction to biostratigraphy, Chapter 4). The last of Coquand's rudist levels (his Dordonian) lies on soft chalk containing *Pycnodonte vesicularis* (his Campanian) and it is a biostrome rich in hippuritids.

2.1.3 Sardinia

The platform carbonates of Sardinia, as described in Busulini *et al.*, 1984, are mainly in the west of the island where they form a very incomplete succession, the youngest beds, as in Provence being Santonian in age. In the east the deposits are mostly pelagic and somewhat more complete. At the top of the Cretaceous strata in the eastern part of the island, there is a conglomeratic unit, known as the Conglomérat de Cuccuru 'e Flores. This contains blocks with rudists and larger benthic foraminifera of purported Campanian and Maastrichtian age. The deposits are not known *in situ* .

2.2 Periadriatic Region: Northern Italy, Dinaric Yugoslavia, Central Italy, Southern Italy

There are large areas of outcrop of Upper Cretaceous platform carbonate in Yugoslavia, Italy and Greece. The sediments were deposited on a series of elongate carbonate platforms which ran NW-SE across the Adriatic area (see figure 2/7 for a detailed map of the present day geography and figure 2/7 for a reconstruction of the location of these platforms).

The Apulian Platform is represented by the deposits of southeast Italy and the Ionian Islands Those of Central Italy belong to the Latium-Abruzzi and Matese Platforms. The Senonian

sequences of these platforms are remarkably similar both to each other and to those of the Dinaric and Adriatic Platforms and are often grouped together as Periadriatic Platforms. The Periadriatic Platforms are remains of the Adrian Promontory, the landmass which included much of Italy which is thought to have jutted out from the African margin into the Tethys Ocean.

2.2.1 Dinaric Platform: External Dinarides

Introduction

Platforms on the eastern side of the Adriatic can be divided into two main areas: the Adriatic and Dinaric platforms. The rocks are now a part of the Dinaric mountains, whose structures run NW-SE parallel to the Yugoslavian coast, and of the southern Alps with E-W trends. In the Italian/Yugoslav border area the alpine trend may be superimposed upon the dinaric trend. The direction of the present day structural trends, which are a result of Tertiary tectonics, is closely related to the pre-existing fault pattern which had governed the distribution of the platforms and basins.

The Dinaric Platform is exposed in the coastal zone of the Dinaric Mountains, which are known as the External, or Outer Dinarides (also known as the zones of External, Internal and Pre-Karst). In terms of the present day geography of Yugoslavia and Italy, these areas form the Trieste area of Italy, western Slovenia, and the coasts of Croatia (excluding most of the Istrian Peninsula), Herzegovina and Montenegro. The Dinaric Platform then continues south-eastwards through Albania into Greece. The Adriatic Platform lay on the south-western side of the Dinaric Platform, in areas now mostly beneath the Adriatic sea but it is visible at its northern end in the south-west of the Istrian Penisula and in Friuli in northern Italy, the latter exposures being in the Carnian Prealps.

The rocks of the Adriatic and Dinaric platforms are generally pure carbonates and these platforms are thought to have been oceanic platforms. They may have been at some distance from the rest of the southern margin of Tethys and were separated by a series of basins in which was trapped any clastic material. The pure carbonate deposits of the Adriatic and

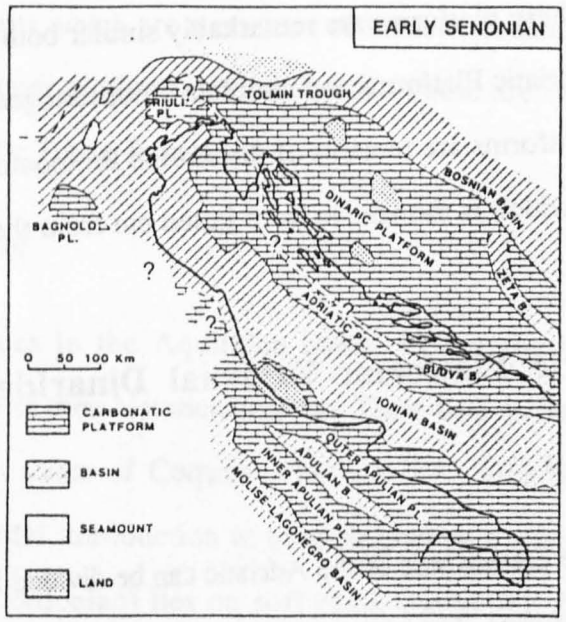


Figure 2/8. Palaeogeographic map reconstructing the probably position of carbonate platforms in the Adriatic area. From Cati *et al.*, 1987

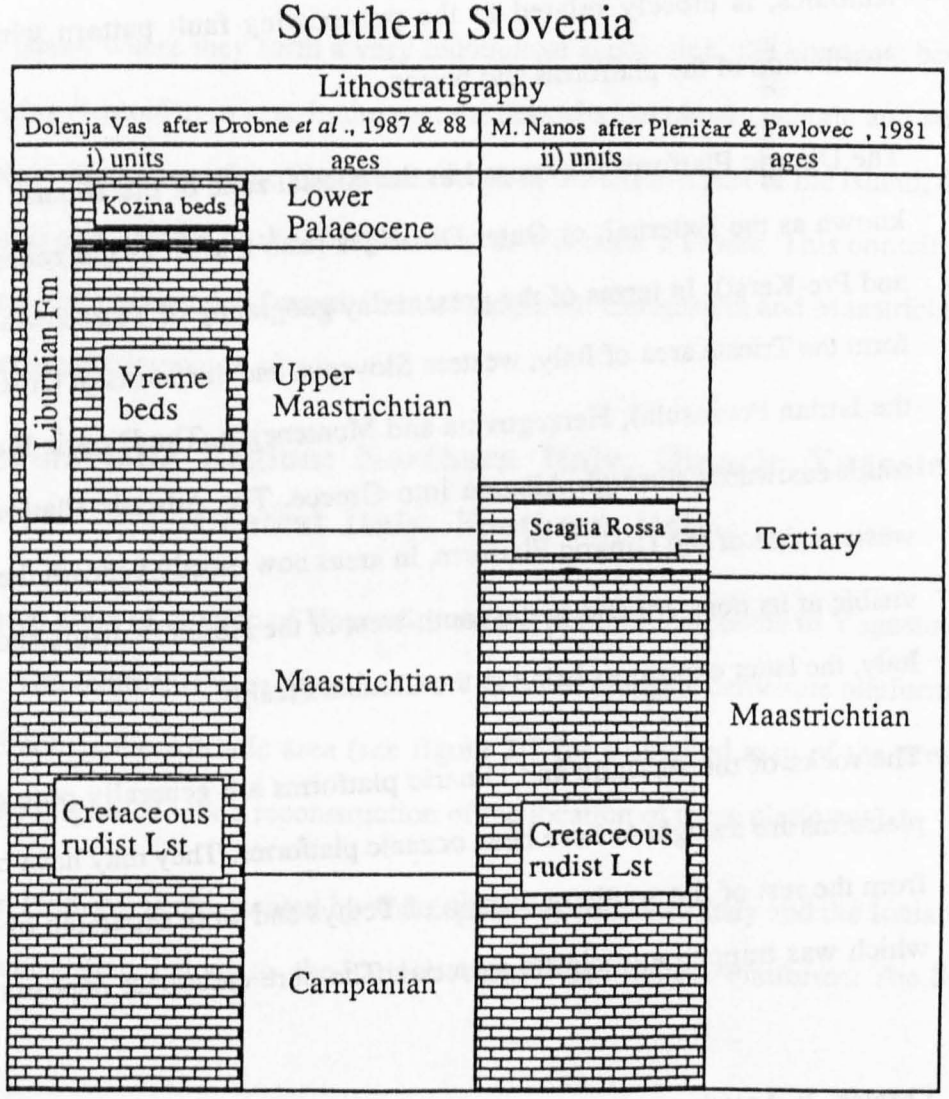


Figure 2/9

Dinaric platforms of the External Dinarides and Southern Alps differ considerably from the platforms preserved in the Internal Dinarides where the sequences include various clastic (including volcaniclastic) lithologies. The Internal Dinaride sequences thought to have been the deposits of a series of island arcs situated above the subduction zone on the northern margin of Tethys and are discussed in section 2.4. More information about the relationship between the Periadriatic carbonate platforms can be found in the following works (on which most of the foregoing discussion was also based): Radoičić 1982: Cati *et al.*, 1987; Cousin & Fourcade 1982; Cavallin & Pirini Radrizzani, 1983; Buser 1987.

2.2.1a Southern Slovenia (Nanos, Dolenja Vas)

In south-west Slovenia, Istria (part of Croatia) and the adjacent area of Italy around Trieste, there is a large area of outcrop of the Dinaric Carbonate Platform. In some sequences in the north and east of the region, the Cretaceous limestone terminates with an unconformity and is overlain by pelagic marls of the Scaglia Rossa. Such areas probably lay near to the edge of the platform. An example of one of these sequences, where the uppermost Cretaceous strata were thought to be Maastrichtian in age is M. Nanos. The rudists are well documented in the works of Mario Pleničar (Pleničar, 1973, 74, 75, 77, 79, 83, 85; Pleničar & Pavlovec, 1981; Pleničar and Šribar, 1983). The account of the biostratigraphy is derived mainly from Pleničar & Pavlovec, 1981. To Pleničar and to Peter Skelton I am grateful for the samples for Sr-isotope analysis from M. Nanos.

M. Nanos is very similar to M. Jouf (see section 2.2.2) in its structure as an overturned anticline of Cretaceous limestone thrusted at the base over Scaglia Rossa (although the structures trend NW-SE and thrusting is to the SW in line with dinaric, rather than alpine trends). Only the uppermost beds of rudist limestone with its diverse fauna of large-sized hippuritids and radiolitids is relevant to the present discussion (see section, fig. 2/9). The rudist beds have a collection of benthic foraminifera, mainly miliolids and textulariids together with some dasycladacean algae.

In more internal parts of the platform, such as represented by the Istrian Peninsula, shallow water limestones extend up into the Lower Eocene. Historically the beds spanning the

interval at the very top of the Cretaceous and the lower part of the Tertiary are known as the Liburnian beds, or Liburnian Formation, following the Austrian geologist, G. Stache, who studied the area towards the end of the last century. This discussion of the stratigraphy of the Liburnian Formation is taken from Bignot, 1972. Defined by Stache in 1872 as the Liburnian Stage, the lower rudist-bearing unit came to be known as the *"Mittlere Foraminiferenkalke"* (Stache, 1889, cit. Bignot, 1972). It contains the foraminifers named by Stache *Rhapydionina liburnica* and *Rhipidionina liburnica* . Rudists were first recorded by Munier-Chalmas, who cited *Radiolites* and/or *Sphaerulites* , but now most of the Liburnian forms go under the name of *Gyropleura* , or *Bournonia* (as identified by Pleničar). Overlying this, the middle unit is a charophytic limestone and the upper unit contains Stache's foraminifera *Coskinolina liburnica* (mainly recognised today as Lower Eocene). In northern Istria (where the sequence is more complete than in the south), the Mittlere Foraminiferenkalke lies on beds with the foraminifer *Keramosphaerina tergestina* Stache as well as orbitoids, which itself lies on rudist limestones of presumed Turonian and Early Senonian age. Following the work of Pavlovec (1963 - cit. Bignot, 1972), who redefined the Liburnian Formation using definite type sections, the lower part of the Liburnian has also been called the Vreme beds and the Middle part the Kozina beds (a term also used by Stache, but sometimes for the Lower and Middle together).

The Vreme beds, although they also contain rudists, are quite distinct from the underlying rudist limestone. The main rudist limestone is white and massively bedded with a diverse assortment of large-sized radiolitids and some hippuritids, whereas the Vreme beds contain an impoverished collection of small-sized radiolitids and requieniids and the facies, being a fine-grained grey limestone, is quite different. There is generally a clear unconformity between the two, the extent of the lacuna varying between localities. There is also generally thought to be another unconformity, between the top of the Vreme beds and the Tertiary portion of the Liburnian Formation.

Recently a sequence covering the top of the main rudist limestone, the Vreme beds and the Tertiary Kozina beds without apparent unconformities has been described from Dolenja Vas, near Senožece, in southern Slovenia. This lies a short distance south-west of M. Nanos and

is thought to have lain in quieter water in an intrashelf basin on the Dinaric Platform. The sequence at Dolenja Vas aroused interest because it was thought that it might be complete across the K/T boundary and preserve some of the youngest rudists. It was documented by Drobne *et al.*, (1987, 88) and the rudists were described in this work by Mario Pleničar and the late Maria Zucchi-Stolfa.

At Dolenja Vas only the uppermost 12m of the Cretaceous portion are described in detail (fig. 2/9). The underlying beds, thought to represent the main rudist limestone as exposed on M. Nanos are said to be grey micritic and sparitic limestones with a moderately diverse fauna of radiolitids. The next beds, the Vreme beds are grey-brown and black micritic limestones with some radiolitids and a level of synsedimentary breccia which includes other radiolitid species. The Vreme beds are overlain (without any noticeable unconfomity) by the Kozina beds which are rudist-free dark-grey to brown marly micrites with stromatolitic layers.

2.2.1b Croatia-Hercegovina-Montenegro (Brač, Hvar, Fundinia, Pelješac Peninsula)

The major area of outcrop of the Dinaric platform is along the Yugoslavian coast, from Istria as far as the Pelješac Peninsula. These areas represent inner parts of the platform in comparison with M. Jouf and M. Nanos in that the Cretaceous rudist limestones are overlain by Tertiary shallow water limestone rather than by pelagic Scaglia Rossa. The limestones are similarly pure, in that they lack a clastic component but they may be more bituminous and dolomitized and therefore are not always white in colour.

According to Polšak and Mamužić (1969), the lithology is generally monotonous but outcrops can be correlated using rudist biostratigraphy without great difficulty. According to these authors the youngest level is found exclusively on the island of Brač in Croatia. The next youngest is present on Brač and the neighbouring island of Hvar, on the Peljašac Peninsula and at Fundinia, east of Titograd in Montenegro. (There are now reasons to doubt the validity of this correlation, see under biostratigraphy.) A more recent list of the rudist fauna of Brač Island comes from Pejović and Radoičić, 1987 which also introduces new

Brač Island, Croatia

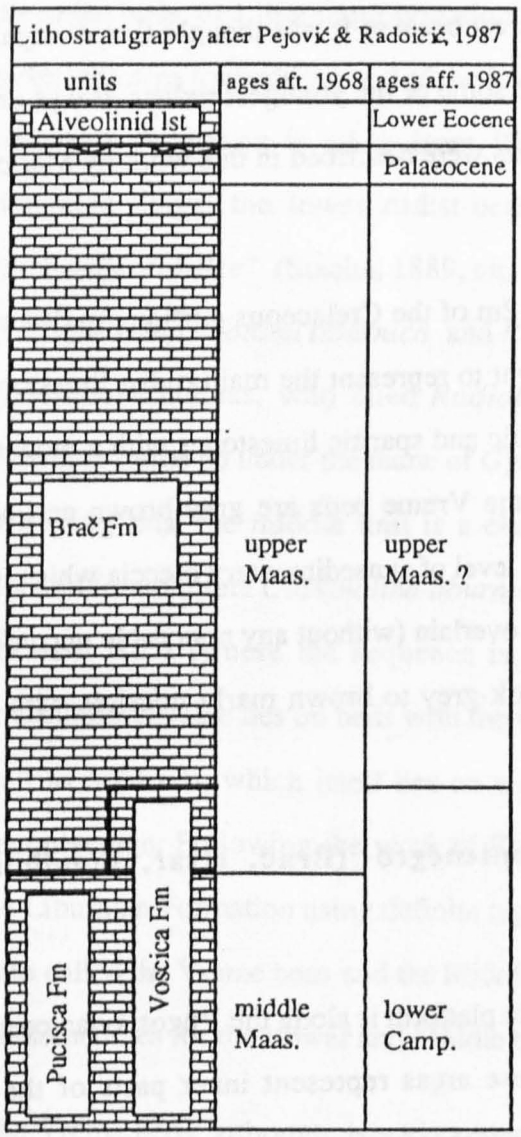


Figure 2/10

M. Jouf, N. Italy

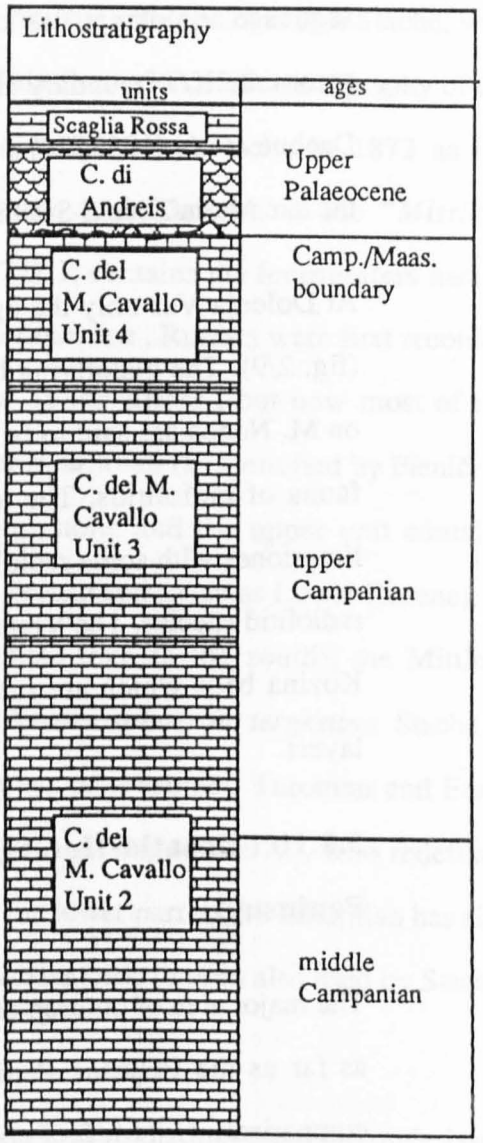


Figure 2/11

Murges, S. Italy

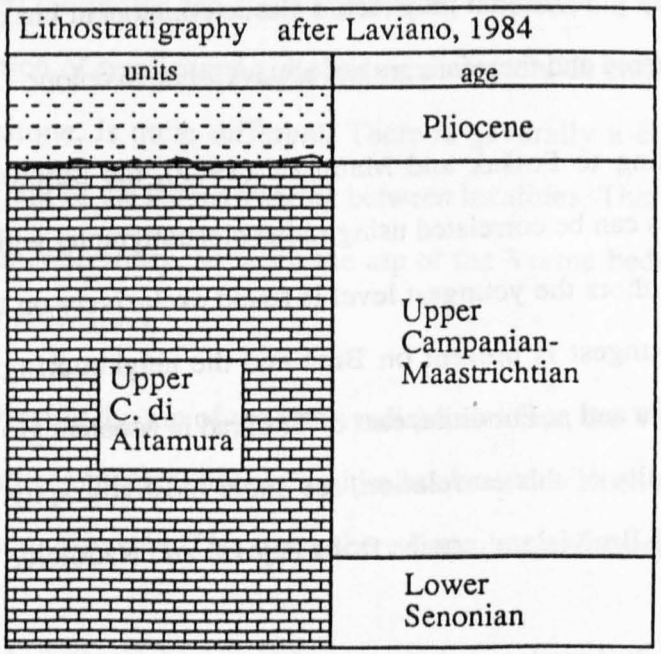


Figure 2/12

stratigraphic subdivisions. Lithological details are derived from Jelaska *et al.* 1983. The description of the stratigraphy of Hvar comes from Sladić-Trifunović, 1980.

I will begin the description of the uppermost part of the limestone sequence as exposed on Brač island (fig. 2/10) with the rocks of the Pučišća Formation, which are around 30m thick. These sediments are mainly packstones-grainstones (with rarer wackestones) made from pellets, benthic forams with occasional dasycladacean algae, and echinoderm fragments and with scattered rudists (floatstone). Fenestrae, minor dolomitization and some cryptalgal laminite beds also lead to the conclusion that the water depth was very shallow, in the sub- to intertidal zones. The lower part of this formation is also sometimes referred to as the Brač marble, a unit with large scale (2-3m) cross-bedding. A lateral equivalent of the upper part of the Brač marble is the so-called Rasotica facies, which is a part of the Pučišća formation. This facies contains a numerous and diverse collection of rudists (mainly radiolitids) lying in biostromes in a very bituminous-rich matrix.

Overlying the Pučišća Formation is the Brač Formation, about 80m thick. This has roughly the same collection of lithologies, but with more cryptalgal laminites and extensive dolomitization. The facies is generally representative of sub- to supratidal environments. The Pučišća and Brač Formations thus demonstrate a regression which culminated locally in sediments with fresh water ostracods and charophytes of probable Palaeocene age. At most localities on Brač, the top of the Brač Formation has a clearly karstified top (although this cuts at different stratigraphic levels) which is filled with bauxite and overlain by an alveolinid limestone of Lower Eocene age. The alveolinid limestone and the topmost part of the Brač Formation are the middle and lower parts of the Liburnian Formation respectively.

2.2.2 Adriatic Platform: Southern Alps

2.2.2a Northern Italy (M. Jouf)

Sedimentation at the northwestern edge of the Adriatic carbonate platform is recorded in the rocks of the Carnian Prealps in northern Italy. The youngest of the white Cretaceous limestones of this region are found north of the town of Maniago on Monte Jouf where they

are overlain by a limestone megabreccia and then by Scaglia Rossa both of Tertiary age. "Maastrichtian" rudists were first described from this locality at the turn of the century and include two genera *Joufia* (Böhm, 1898) and *Colveraia* (Klinghardt, 1921) for which M. Jouf is the type locality. Since these descriptions M. Jouf has not been the subject of major geological investigation. The following account comes from my own work there in 1986-1988 which can be read in detail in Swinburne & Noacco, (in press), a copy of which is available in the appendix (see introduction regarding the involvement of Noacco).

The uppermost three of the four limestone units described in that account are relevant to this work (see fig. 2/11). The first of these, Unit 2 (about 350m thick) is clearly a regressive sequence. The lowermost beds are forampelbiomicrite packstones and grainstones, rich in rudist biostromes and debris. Rudist beds become less frequent going upwards in the unit, the beds become generally thinner and there is a higher proportion of micrite matrix. Laminated intervals, birds-eyes, dolomitisation and intraformational conglomerates become progressively more common towards the top of Unit 2, where sediments are characteristic of the inter and supra-tidal zones. In the next unit, Unit 3 (around 80m thick) dense biostromes dominated by the radiolitid *Bournonia excavata* appear. The change in facies to Unit 4 (probably around 40m thick) is marked by an intraformational conglomerate above which the sediment is considerably coarser than in previous units (rudite rather than calcarenite grade). It is made of coarse rudist debris, echinoid spines, broken orbitoids and globotruncanids and contains a numerous and diverse rudist fauna with many large radiolitids. These characteristics are reminiscent of a platform margin facies where the rudist fauna thrived in turbulent conditions. There are several horizons of penecontemporaneous dissolution in Unit 4 indicating frequent emergence of the facies.

2.2.3 Apulian Platform: Southern Italy, Ionian Islands

A large part of southern Italy is made from Upper Cretaceous platform carbonates of the Apulian Platform with a major unconformity between these and the overlying deposits which are Pliocene in age. The area is in the province of Puglia, (or Apulia in the Roman form) and includes the "heel" of Italy, or the Salentine Peninsula, in southern Puglia, the promontory

of Gargano and the rocks slightly further south near the town of Ostuni. The deposits also continue underwater into the Ionian Islands of Greece.

The sequences of the Ostuni area have been described most recently by Laviano (1984 & 1985). The Gargano rocks are slope carbonates thought to have been derived from the lateral equivalent of rocks which can be seen today *in situ* at Ostuni. Their description come from Borgomano & Philip, 1987. Studies in the Salentine Penisula come from Cestari & Sirna, 1987.

2.2.3a Murges

In the Ostuni area the latest Cretaceous deposits are included in the Calcari di Altamura (see fig. 2/12) although other authors (such as Campobasso, 1972) have used the synonymous term Calcari di Ostuni. Laviano (1985) describes the sequence which outcrops on the road from Ostuni to M. San Oronzo (Stradi dei Colli section) together with some near the coast near Massia Gorgognolo which correspond to the upper part of the Oronzo succession (and which is the only part of the sequence relevant to this discussion).

Beds underlying the main rudist buildup are calcarenites and calcirudites with prominent *Thalassinoides* and *Skolithos* burrows. This suggests low sedimentation rate and restricted circulation. This is followed by a dense accumulation (biostrome?) of the small hippuritid *Hippurites nabresinensis* with intervening micite-rich sediment in unit also assumed to be Lower Senonian. Overlying this is another calcarenite-calcirudite unit with several hardground surfaces, burrows and the rudist fauna of purported Upper Campanian-Maastrichtian age. In the lower 10m poorly preserved *Sabinia* valves are found along with small colonies of branching corals. The next 30m are coarser (calcirudite) with eroded and shattered valves of *Mitrocaprina* and *Joufia*, the trace fossil *Planolites* and some echinoids. The sediment is mainly packstone with some grainstone and made mainly from benthic foraminifera, partially bored and micritised megafossil fragments and some pelagic calcispheres.

The rudist limestone is overlain by a few metres of non rudist-bearing pelagic/slope limestone of Cretaceous age ((P.W. Skelton, pers. comm.).

2.2.3b Gargano

The Gargano Promontory is made mostly of Upper Jurassic-Lower Cretaceous limestones and in these a gradation of facies from *in situ* platform carbonates to slope carbonates to basinal pelagic deposits can be seen from southwest to northeast (see figure 2/13). Of the Upper Cretaceous sediments there are no *in situ* carbonates but slope and basinal deposits are found in the area of Monte San Angelo where they constitute the Caramanica formation (figure 2/14). The slope deposits consist of talus beds made of conglomerates with a wide range of grain sizes. These were deposited by a variety of depositional mechanisms such as rock falls, slides, grain flows, turbidites and debris flows. The largest blocks may be up to 20m diameter. The source material for the blocks found in the slope deposits are thought to be the platform carbonates at Ostuni.

In the blocks Borgomano & Philip found massive and tabular biostromes consisting mainly of *Hippurites* and *Joufia* . Other blocks contained large *Sabinia* shells, some up to lm long. These co-occured with small individuals of *Joufia* and abundant gastropods in a wackestone-packstone sediment. The *Sabinia* colonies were thought to represent shelf edge facies whilst the *Joufia-Hippurites* facies came from relatively more internal parts of the platform.

2.2.3c Salento

Relevant strata outcrop across the entire Salentine Peninsula, but because they are so flat lying, as is the topography, most attention has been paid to quarry and coastal sections (see section, fig. 3/15). These sections can be conveniently divided into two areas on the basis of facies. In the Poggiardo-Santa Cesarea Terme area, which is on the eastern, Adriatic side of the peninsula, there are deposits characteristic of the shelf edge. These consist of numerous local patch "reefs" of rudists, gastropods and echinoderms with a rich fauna of benthic foraminifera - miliolids, textulariids and rotalids - and ostracods. The rudist fauna is of large

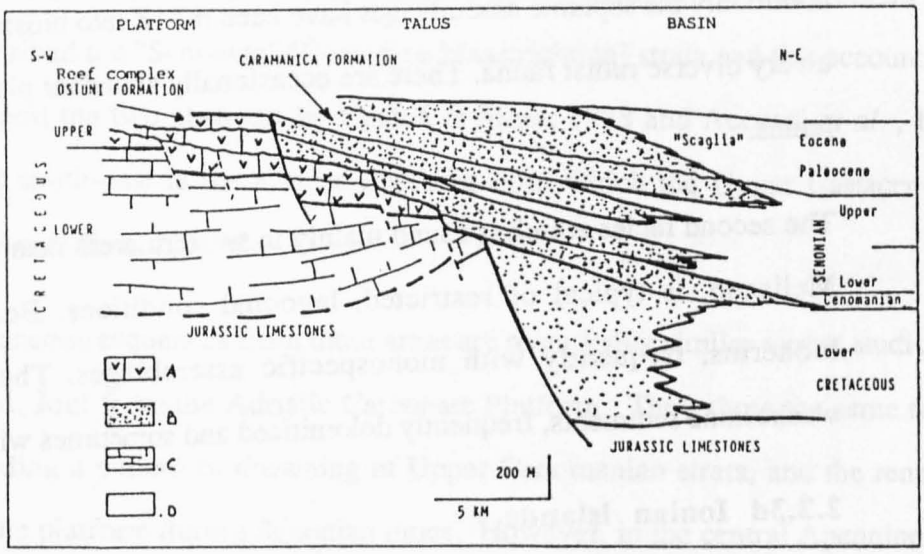


Fig. 2 - Tecto-sedimentary and stratigraphic organization of the Gargano-Apulian carbonate margin during the Cretaceous. A: Upper Cretaceous carbonate platform and reef formations, B: brecciated and bioclastic carbonate formations of slope deposits, C: lower Cretaceous carbonate platform formation, D: basinal carbonates.

Figure 2/13. Interfingering of talus with basinal deposits at Gargano. From Borgomano & Philip, 1987

Gargano, S. Italy

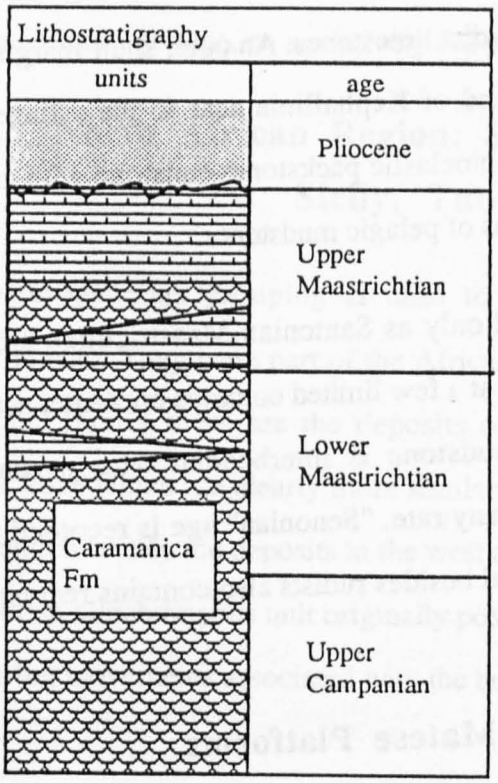


Figure 2/14

Salento, S. Italy

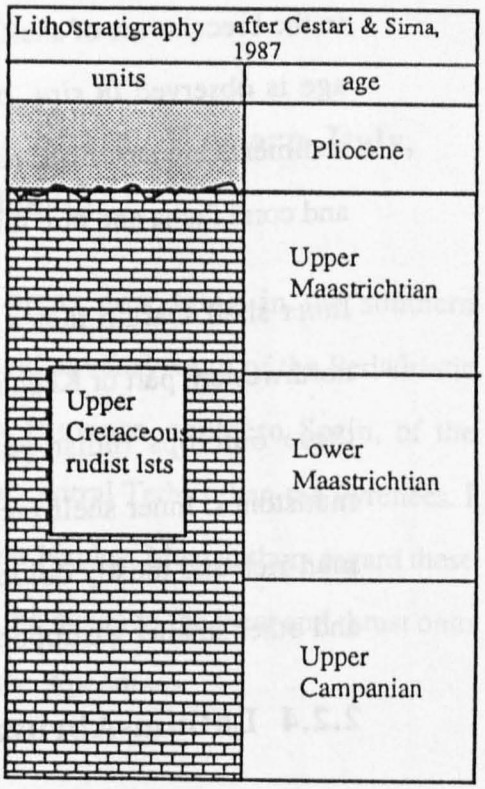


Figure 215

radiolitids, some canaliculate rudists and rarer hippuritids. When the communites are preserved *in situ* there are major local variations in facies from mudstone-wackestone (presumably sediment baffled by the rudists into mounds) to rudstone, though more commonly the separate assemblages have been mixed into biostromes. Overall the facies has a very diverse rudist fauna. There are occasionally abundant planktonic foraminifera in this facies.

The second facies which is found mainly in western areas near the Ionian sea, such as near Melisano, is typical of restricted, lagoonal conditions. Beds commonly have rudist bioherms, frequently with monospecific assemblages. These are found in muddier wackestone sediments, frequently dolomitized and sometimes with small gastropods.

2.2.3d Ionian islands

Maastrichtian rudists have been reported from the Ionian Islands of Zante, Kephalina and Lefkas. This account of those stata is from Accordi *et al.* 1987.

The deposits are separated into foreslope, shelf margin and inner shelf facies and probable Maastrichtian rudists come from all three. In the southwest part of Lefkas there are limestone breccias interbedded with pelagic mudstones and graded bioclastic grainstones. The blocks in the breccias are of shelf margin rudist limestones. An outer shelf margin facies of similar age is observed *in situ* on the island of Kephallinia near to the village of Harakti. The sediments are described as massive bioclastic packstones-rudstone with an abundant rudist and coral fauna and rare intercalations of pelagic mudstones.

Inner shelf margin facies identified only as Santonian-Maastrichtian are recorded in the northwestern part of Kephallinia and at a few limited outcrops on Zante, near Anafonitria. In these outcrops rudist grainstone-rudstone is interbedded with partially dolomitized mudstones. Inner shelf facies of, at any rate, "Senonian" age is recorded from Zante. It is mud-rich and mostly dolomitized and besides rudists also contains recrystallised nerineids and other smaller gastropods.

2.2.4 Latium-Abruzzi and Matese Platforms

In the central Apennines of Italy can be found the remains of various carbonate platforms very similar to those described as "Periadriatic" platforms. One of these lies to the north-east of Rome and is known as the Latium-Abruzzi Carbonate Platform. Various workers from Rome have described the "Senonian" [Coniacian-Maastrichtian] strata and this account uses Mariotti, 1982 and the two abstracts by Cestari & Sirna, 1988 and Accordi *et al.* , 1988. Slightly further south-east is the Matese Platform from which the Upper Cretaceous is documented in Accordi *et al.*, 1982.

The Upper Cretaceous sequences from these areas are remarkably similar to that studied by this author on M. Jouf from the Adriatic Carbonate Platform. They show the same facies sequence, recording a pattern of drowning of Upper Cenomanian strata, and the renewed outbuilding of the platform during Senonian times. However, in the central Apennines the last rudists are usually in strata which on M.Jouf were dated as mid-Campanian and so most of the sequence is outside the scope of this study. Two exceptions to this are the beds documented by the recent work by Accordi *et al.* (1988) where a*Sabinia-Joufia-Pironaea* assemblage was found at the top of the sequence on M. Maiella, and the presence of *Pseudopolyconites* in the Simbruni-Ernci and Lepini Mnts recorded by Cestari & Sirna, (1988). Accordi *et al.* consider their assemblage to have inhabited an environment near to the sediment-water interface, on a relatively flat platform.

2.3. North African Region: Southern Spain, Western Italy, Sicily, Tunisia, Algeria

This heterogeneous grouping is used to describe areas now lying in the southern Mediterranean. They were part of the African margin and situated south of the Periadriatic Platforms. Firstly there are the deposits of Valencia Province, southern Spain, of the Prebetic zone which are clearly more similar to those of central Tethys than the Pyrenees. I will mention briefly the deposits in the west of Italy, near Naples. Most authors regard these as part of an allochthonous unit originally positioned in the ocean to the west and thrust onto Italy during movements associated with the building of the Apennines.

The western Sicily deposits are referred to as part of the Ilbéen domaine, which is another autochthonous unit. Authors disagree about its original palaeogeographic relationship to the other structural blocks (Camoin *et al.* , 1983). D'Argenio *et al.* (1980 - cit. ibid.) would associate it primarily with the periadriatic platforms (the structural unit of Adria) whilst Biju-Duval *et al.* (1976 - cit. ibid.) consider it to be most closely related to the African margin with a basin between this and southern Adria. On the basis of the fauna, Camoin *et al.* (1983) see strong relationships with both areas, but the closer one with Adria.

There are many rudist-bearing carbonate platforms on the N. African mainland but information about these is limited and only those from Tunisia, for which there is detailed lithological information, are discussed in this chapter.

2.3.1 Southern Spain

There are several localities in southern Valencia Province in south-east Spain which have yieded purported Campanian-Maastrichtian rudists. These are mentioned in Pons and Vicens, 1988 as being located in the zone encircled by Alzira, Xàtiva and Gandia and include the locality of Quatretonda. The existence of this locality has been known since the turn of the century when Nicklès (1892, cit. Philip, 1985a) first recorded the central Tethyan genus *Pironaea* at Quatretonda. The locality has been subsequently described by Philip (1985a) which is the source of this material. Other rudist species from these localities are currently being studied by Pons & Vicens.

Situated north of the village of Quatretonda, and equidistant from Barchetta and Lucente, the Upper Cretaceous sediments are unconformably overlain by Tertiary deposits of the Quatretonda Plain. Sediments of Campanian and Maastrichtian age are described in three formations, the Chame, Bastida and Torrella Formations (see fig. 2/16), the upper two of which contain rudists, and the thickness of rudist-bearing strata being about 180m. The lithologies are a mixture of carbonate, which predominates, and detrital sand and clay. The higher the detrital content, the nearer shore the facies is thought to have been deposited. Philip interprets the sedimentation in terms of large scale transgression-regression cycles

Quatretonda, S. Spain

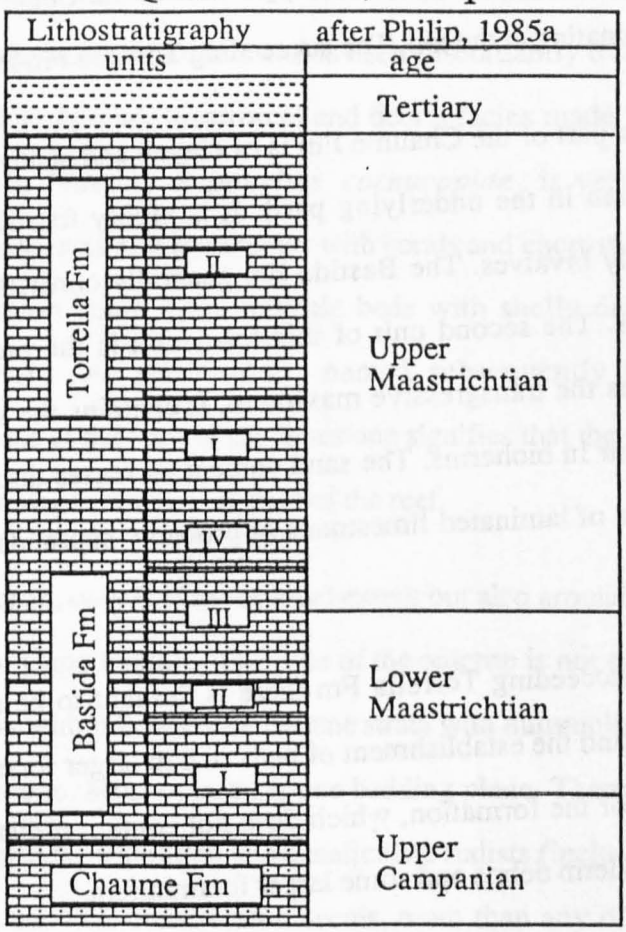


Figure 2/16

Sicily

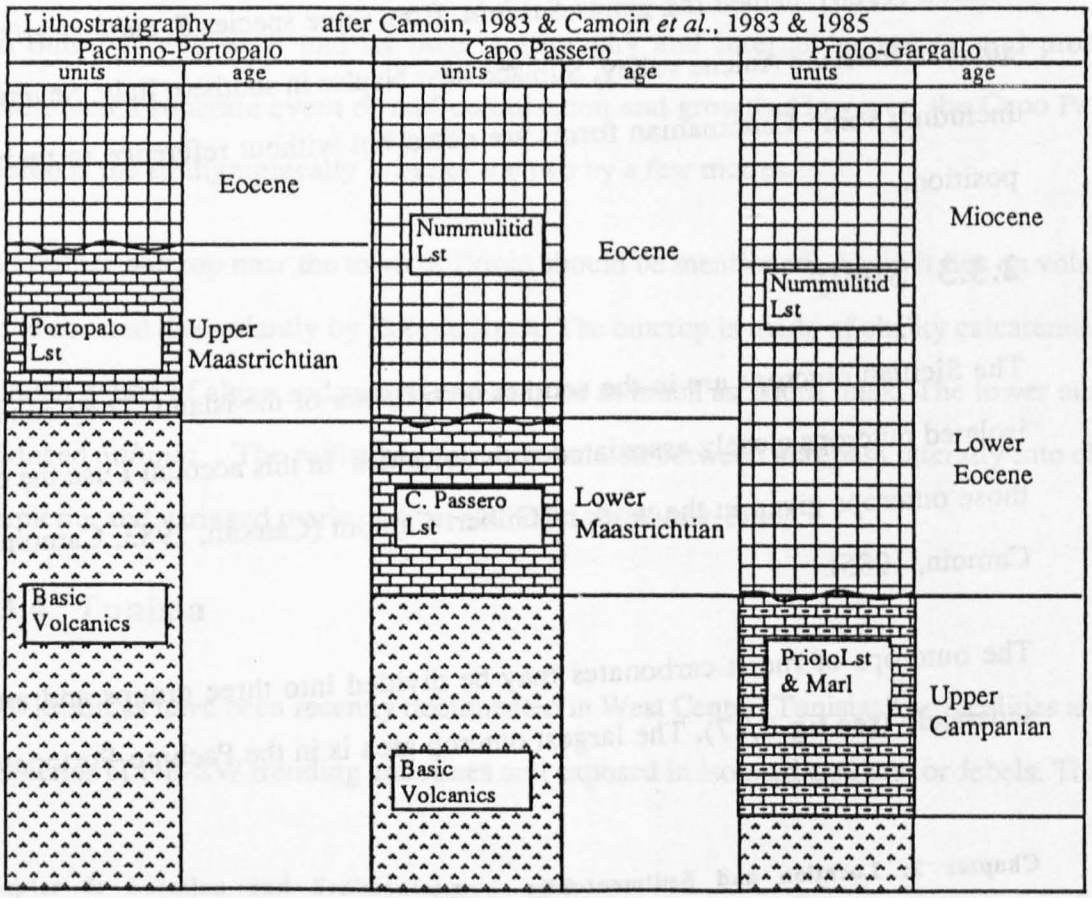


Figure 2/17

with a regression throughout the upper half of the Chaume Fm and throughout the Bastida Fm, culminating at the top. The succeeding Torrella Fm is thought to be transgressive.

The upper part of the Chaume Fm is of clayey and sandy limestones (but with less detrital content than in the underlying part). It is highly fossiliferous and rich in shelly debris, particularly bivalves. The Bastida Fm generally consists of sandy and sometimes clayey limestones. The second unit of this formation is the purest limestones of the sequence, regarded as the transgressive maximum. It contains the specimens of *Pironaea* , some of which occur in bioherms. The sand content increases throughout units III and IV with the appearance of laminated limestones of probably supratidal origin at the top of the Bastida Fm.

With the succeeding Torrella Fm there is thought to be a sudden return to more marine conditions and the establishment of beds rich in larger foraminfera and then radiolitids. The upper unit of the formation, which does not contain rudists is mostly bioclastic limestone with echinoderm debris and some larger foraminifera.

2.3.2 Western Italy

Parona (1908) named the genus *Sabinia* from three species *S. sublacensis* , *anienis* and *sinuata.* from the Aniene valley, Subiaco near Naples in southern Italy. Several other rudists including some Cenomanian forms are noted but without reference to their stratigraphic position.

2.3.3 Sicily

The Sicilian outcrops are in the southeastern corner of the island. They consist of several isolated outcrops closely associated with volcanics. In this account I use the description of those outcrops given in the work of Gilbert Camoin (Camoin, 1983, Camoin *et al.*, 1983; Camoin, 1985).

The outcrops of rudist carbonates may be divided into three groups and are considered separately (see fig. 2/17). The largest outcrop area is in the Pachino-Portopalo area and is

around 9km^2 and about 20m thick. The Cretaceous limestone covers a basic volcanic basement, which is altered at its surface and is itself discordantly overlain by Eocene strata. There is a variety of biohermal, biostromal and debris facies made from rudists and larger benthic foraminifera. Notably *Hippurites cornucopiae* is very abundant as a major contributor to both bioherms and biostromes with corals and encrusting red algae. At the top of the rudist succession come more micritic beds with shelly debris, gastropods and a species of *Apricardia* , *A. pachiniana* named subsequently by Sirna (1983). The deformation of the beds at the base of the limestone signifies that the volcanism was active at least during the early stages of development of the reef.

A much smaller outcrop, only 0.5km^2 in areal extent but also around 20m thick, is found on the adjacent island of Capo Passero. The base of the outcrop is not exposed, but laterally the limestone interfingers with pillow lavas. Eocene strata with nummulites discordantly overlies the Cretaceous limestone. Most outcrop is one bedding plane. There is a diverse assortment of rudists with hippuritids, radiolitids and canaliculate rudists (including *Sabinia*) as well as massive coral colonies. This construction seems, more than any of the other examples, to merit the term reef as it probably had some original relief. Although only a hundred metres from the outcrop on the coast at Pachino, Camoin (1983) found no reason to correlate the two outcrops and each had its own stratigraphy and internal geometry and probably represented a separate event of reef colonisation and growth. However, the Capo Passero outcrop is the stratigraphically lower of the two by a few metres.

One further outcrop near the town of Priolo should be mentioned. Again it lies on volcanics and is covered discordantly by Eocene strata. The outcrop is made of chalky calcarenite with rounded debris of algae and rudists and may be as much as 200m thick. The lower unit has produced *Sabinia* . The rudist beds are intercalated between and pass laterally into chalky biomicrite and variaged marls with an abundant planktonic fauna.

2.3.4 Tunisia

Two localities have been recently documented in West Central Tunisia. The localities are part of a series of NE-SW trending anticlines and exposed in isolated outliers, or Jebels. The first

Tunisia

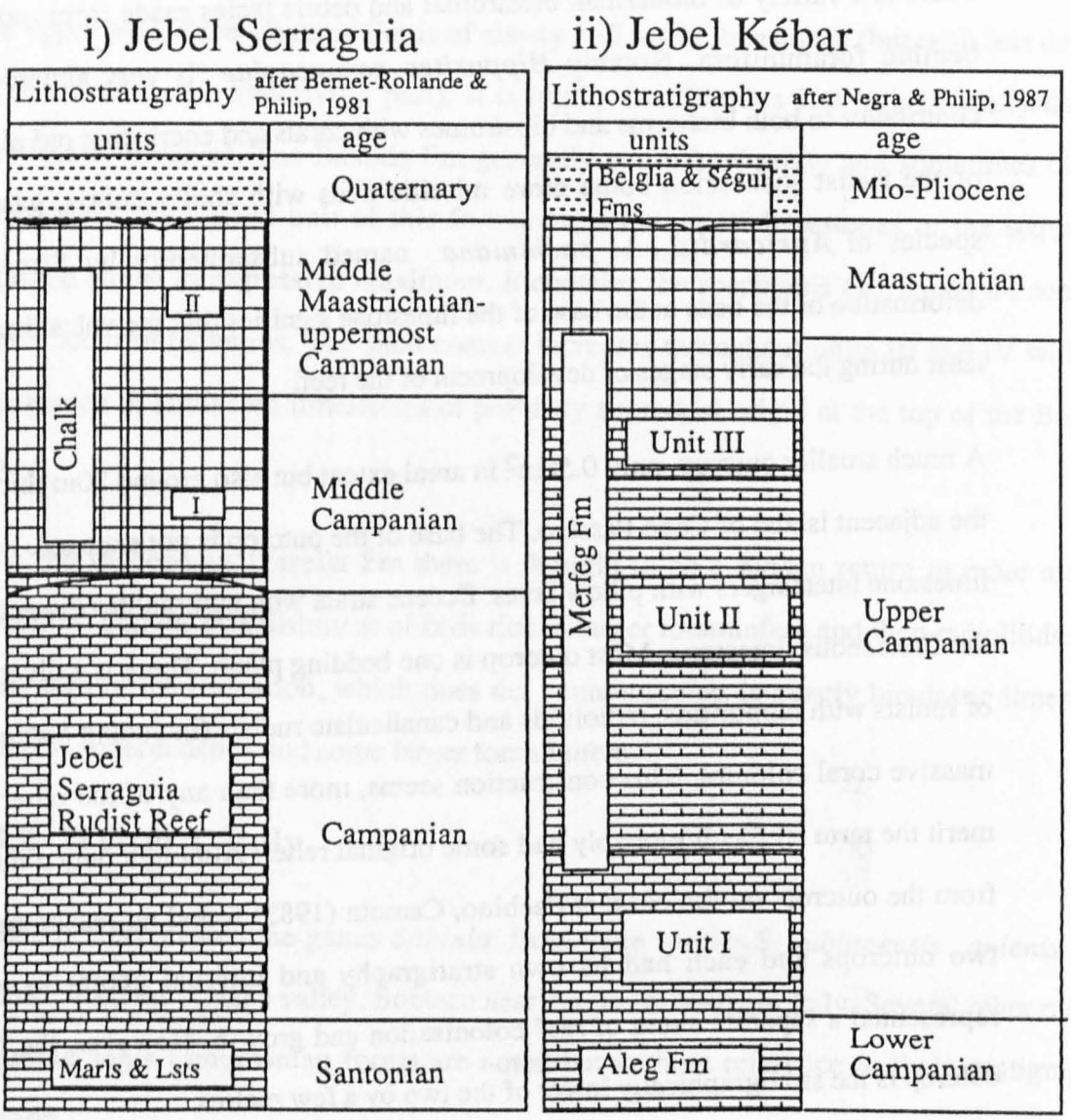


Figure 2/18

of the localities to be described is Jebel Serraguia, which is near to the Algerian border and the second, Jebel el Kébar is about 100km to the west. Jebel Serraguia is a single rudist bioconstruction, but Jebel Kébar is composed of several smaller rudist 'reefs'. The description of the Jebel Serraguia sequence is taken from Bernet-Rollande & Philip, 1981 and the rudists in Philip, 1986 and that of Jebel el Kébar from Negra & Philip, 1987.

In the Jebel Serraguia sequence, the rudist limestone is underlain by marls and bioclastic argillaceous limestones of probably Santonian age, in the core of the anticline. The rudist limestone itself forms a unit about 100m in thickness. It is fairly rich in fossils, yielding corals, gastropods and rudists, such as *Sabinia* and *Joufia* , but the rudist fauna is of low diversity. The fossils vary from whole specimens to coarse angular debris. The rudist limestone is cut by a series of anastomosing channels filled with limestone blocks and often lined by chalky material. In these features they resemble the channels found amongst modern coral reefs.

The rudist limestone is overlain by chalk which appears to wedge out against the irregular topography of the limestone and breccia channels. These three features - the channels, their breccia fill and the disconformable overlay of the chalk all indicate that the original bioconstruction had some relief. [Yet as it does not seem to have been supported by the framework building organisms, but more probably by early cementation of the sediment, it should perhaps be more properly called a mound than a reef.] The 'chalk' is made of two units. Immediately overlying the rudist limestones it is described as a chalky limestone with marl intercalations and inoceramid debris. The next beds are white chalk with flint nodules and inoceramids. This is covered by Quaternary alluvium.

At Jebel Kébar the limestones, which are rich in rudist and corals, comprise the Merfeg Formation (of Khessibi, 1978, cit. Negra & Philip, 1987). This is underlain by marls and argillaceous limestones of the Aleg Fm. It is discordantly overlain by conglomerate, silts and clays of the Beglia and Ségui Fms of Tertiary age.

The Merfeg Fm itself is around 150m in thickness and includes three main rudist lenses separated by argillaceous limestones and cut by channels filled with conglomerates (see fig.

2/18). The base of the first rudist limestone unit is in places highly micritic with sparse rudists and corals, but at its top is almost a framework of colonial corals and rudists. In the middle limestone unit rudists are abundant and well preserved. In the third they are generally sparse, the beds being more generally micritic but in places are rich in rudists and larger foraminifera.

The intervening beds of clayey micritic limestones have yielded planktonic foraminifera and coccoliths. Overlying the rudists at the top of the Merfeg Fm are pink micritic limestones with some flint nodule and inoceramid moulds.

2.3.5 Algeria, Libya

There are undoubtedly similar rudist localities in other north African countries, but without detailed stratigraphic information. For example, one rudist, *Praeradiolites pulchellus*, regarded as Maastrichtian in age was recorded by Emberger (1954) from the Hodna Basin, Algeria.

2.4. Balkans-Eastern Alpine Region: Western Serbia, Eastern Serbia, Bulgaria, Romania, Slovakia, Austria & Hungary

The rocks of these areas are not as well known as those in Italy in terms of their sedimentology and in reconstructions of the palaeoenvironment and palaeogeography. Yet sequences from the Internal Dinarides are unquestionably quite different to those of the External Dinarides. In the latter, the rocks are mostly pure carbonates and therefore laid down in some kind of oceanic setting far from land. In contrast, in the Internal Dinarides there is a variety of lithologies including sandstones, marls and volcaniclastic sediments as well as limestones. These are thought to be the deposits of island arcs which formed off the northern margin of Tethys over the subducting northern slab while flysch accumulated in and around the trench (Polšak, 1979). The rocks of eastern Serbia and western Bulgaria are very similar in faunal content and in sedimentology and both have lavas and tuffs intercalated in the sequence. They have sometimes been grouped together as remnants of the Pannonian Carbonate Platform. They were certainly part of the northern margin although their position

is somewhat uncertain because there may have been some considerable distance in the late Cretaceous between areas which now make up the External and Internal Dinarides.

Much has been made of the comparison between the eastern Serbian strata and those of the eastern part of the Central Alps, the so-called Gosau beds of Austria (which with one exception probably are not younger than Santonian in age - see under biostratigraphy). These were laid down in various separate basins and were then fractured by Alpine movements so they are difficult to correlate. The Gosau beds in the Austrian Alps together with the Hungarian deposits are part of the Central Alpine zone (Pavlovec, 1979), a region which is most likely to have been part of the northern margin as it now lies north of the Insubric Line, the main junction between the continents. However it is still not impossible that they are parts of the southern margin shunted north, over the main Alpine chain. The Romanian deposits of the Transsylvanian Alps and the Carpathians may be related to these or to the eastern Serbian and Bulgarian sediments.

2.4.1 Inner Dinarides: (Fruška Gora, Dragačevo, Gučevo, Lisa & Kozluk)

The range of the Internal Dinarides (or High Karst) displays the remains of the Dinaric Platform (see figure 2/8 for map of the present day geography of Yugoslavia).This starts in the south in the Montenegro-Albania border area and extends north-eastwards through southern and western Serbia and in Bosnia and probably also includes the limestones of northern Slovenia (which were subjected to Alpine tectonics and are now a part of the Julian Alps). The rudists are documented in the works of Branislav Milovanović and in those of his successor Mileva Sladić-Trifunović but usually without details of the lithostratigraphy. The West Serbian localities of Dragačevo, Gučevo and Lisa and those of the Fruška Gora region are frequently cited in the works of both these authors. The outcrop at Bešpelj, north of Jajce, in Bosnia is described in Polšak, 1965 and that near Kozluk in north-eastern Bosnia in Sladić-Trifunović, 1972. The outcrops in Southern Serbia in the Serbian province of Kosovo at Leposavić are outside the scope of this discussion as are they are generally assumed to reach only the Lower Campanian (see also biostratigraphy).

Internal Dinarides

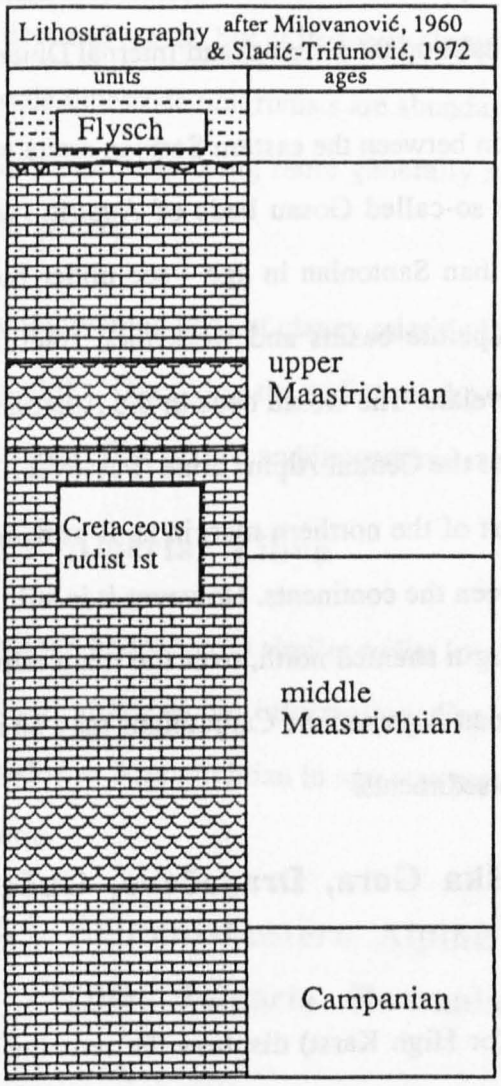


Figure 2/19

Eastern Serbia

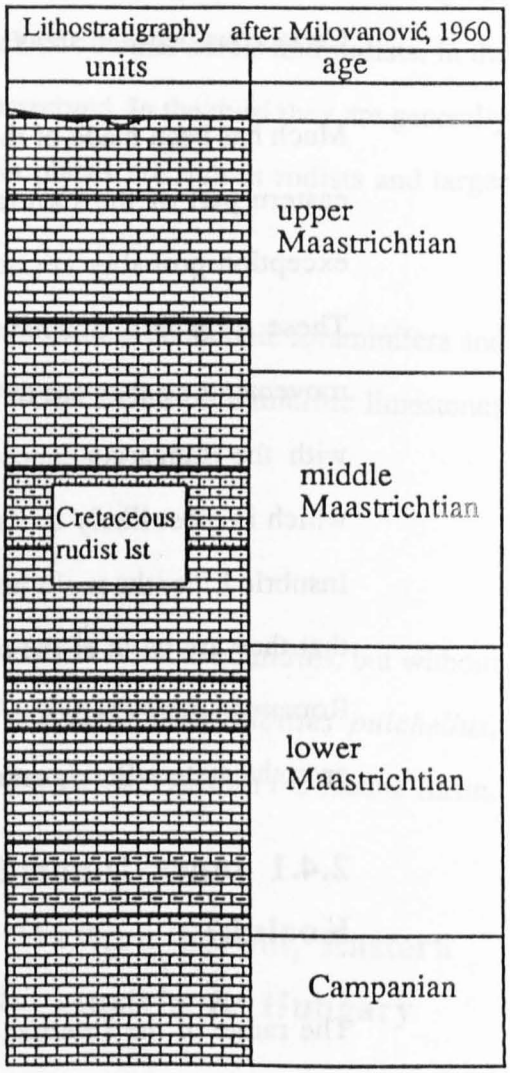


Figure 2/21

Figure 2/20. Senonian section of the locality Vratonjic Krs, western Serbia. Pz=Palaeozoic. 1. Sandy limestones with *Orbitoides media*; 2. limestones with orbitoids, *Radiolites squamosus* and other rudists; 3-6. alteration of the limestones with rudists and orbitoids. after Milovanovic, 1952 in Sladic-Trifunovic, 1983.

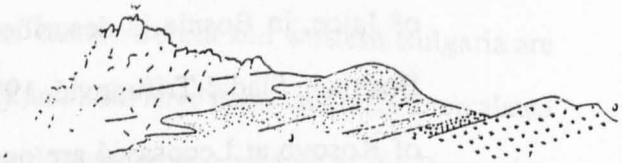


Figure 2/22. Senonian sediments in the east part of the locality Bacevica, eastern Serbia. 1. andesites; 2. andesitic tuffs; 3. sandstones with *Actaonella gigantea*; 4. rudist limestones. after Milovanovic, 1933 in Sladic-Trifunovic, 1983.

In general the Internal Dinaride sequences (see fig. 2/19 have been described as conglomerates (presumbly limestone conglomerates) interbedded with rudist limestones (Milovanović, 1960). The uppermost level of rudist limestone contains the most diverse fauna with *Pironaea* and *Pseudopolyconites* . These beds are overlain by Tertiary Flysch which contains blocks of rudist limestone. The succession at Lisa, western Serbia can be found in figure 2/20 (taken from Sladić-Trifunović, 1983). In the sequence at Bešpelj, north of Jajce, in Bosnia planktonic foraminifera co-occur with the rudists. The only detailed lithological information about the Inner Dinaride sequences is from the Kozluk outcrop. These beds are described as sandy limestones with orbitoids and rudists, large pectinids, ostreids, corals, bryozoa and annelid fragments. Another part of the locality consists of grey bedded and massive limestones. The Kozluk sequence is thought to be very similar to that at Fruška Gora.

2.4.2 Balkans

2.4.1a Eastern Serbia

The rich fauna of eastern Serbia was recorded by Branislav Milovanović (eg. Milovanović, 1935a & 60) and later by Mileva Sladić-Trifunović (Sladić-Trifunović, 1977, 79, 81a). The outcrops, as first described in Milovanović, 1932 are found at the foot of Tupižnica mountain south of the "andesitic" massif of Timok. The localities of Vrbovac and Bačevica are most relevant to this discussion, being of Maastrichtian age. The sediments are underlain by andesites and tuffs and the main part of the succession, which is only weakly stratified is made of a mixture of impure rudist limestones, sandstones with orbitoids and some marls (see fig. 2/21 and 2/22, the latter from Sladić-Trifunović, 1983) . The rudist beds are replaced to the east and west by inoceramid bearing marls.

Milovanović (1935b) noted that the Vrbovac reef consisted of many Senonian (Santonian-Maastrichtian) reefs which overlay the andesite. The entire Maastrichtian with rudists and corals was found only near Bačevica where the most recent part of the "Vrbovac reef" covered around a dozen square kilometres. The "Maastrichtian" and "Upper Campanian"

was made of limestones, sometimes sandy, of reefal breccias and sandstones. The middle part of the Maastrichtian succession had particularly large rudists and in the upper part rudists were so numerous as to make up the entire sediment. Corals, bryozoa and foraminifera accompanyed the rudists.

2.4.2b Bulgaria

Rudist limestones of purported Maastrichtian age are recorded in at least two regions of Bulgaria. Those of the Breznik area in western Bulgaria (Srednogorie) are the better known, but similar sequences have been found more recently near Yambol in central Bulgaria. The rudist fauna has been extensively documented by the works of Pamouktchiev (eg. Pamouktchiev, 1962, 64 & 79a) but the sedimentology of the rudist sequences largely ignored. The lithological information presented here represents the results of a visit made to the rudist localities accompanied by Professor Pamouktchiev in May, 1988. Samples were collected and examined later for foraminifera, identified by Michel Bilotte, and analysed for their strontium isotope ratio, both of which have been used in a redetermination of the age of these localities.

The Campanian-Maastrichtian succession northwest of the town of Breznik includes two main rudist localities (see fig. 2/23). The first is in the hillsides north of the village of Garlo and the second outcrops east of the village of Yaroslavtzi. The two localities are separated by an estimated 2-3km of terrain where unfossiliferous sandstones and subordinate limestones and exposed (and they may be of non-marine origin). Although Yaroslavtzi is up sequence from Garlo there may be major faults between the localities, so that Yaroslavtzi is not necessarily older. The Yaroslavtzi beds are separated by another valley from finely fissile, bituminous limestones and then sandstones of supposed Palaeogene age.

The sequence at Garlo starts with a unit of basic lavas, agglomerates and tuffs exposed at the base of a hillside on a track towards Yaroslavtzi. The volcanics pass into overlying sediments which are organised into cycles each of the order of tens of metres thick. The first four of these cycles are composed mainly of orange pyroclastic and calcareous sandstones. There are thin clayey interbeds, abundant trace fossils on the base of the sandstone beds and

Bulgaria

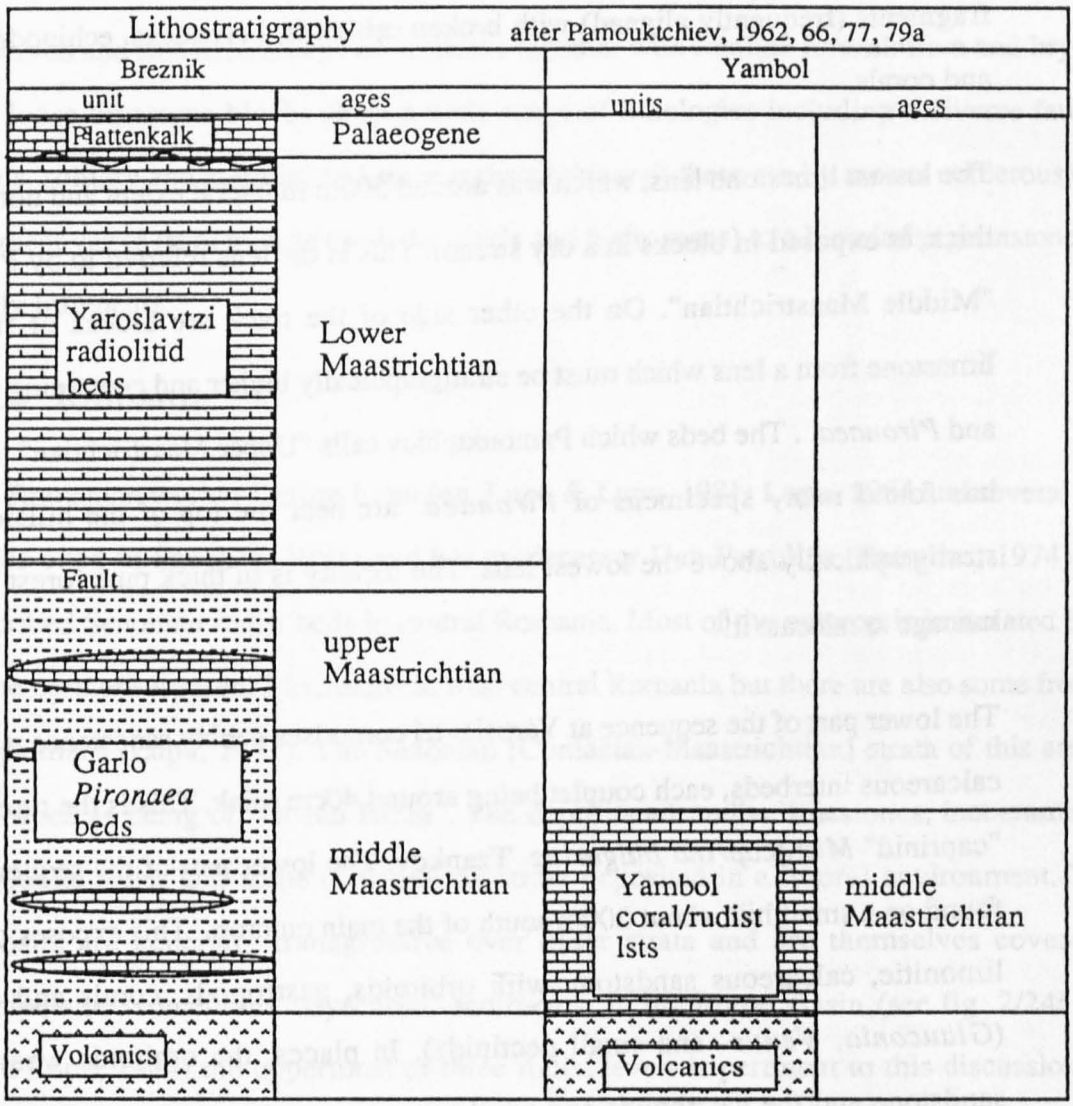


Figure 2/23

occasional bands of quartz conglomerate with well rounded clasts. Limestone is generally a subordinate lithology and forms discrete macrofossiliferous lenses. In section, limestones of the lower lenses are grainstone biosparites made from medium-coarse lamellar rudist fragments (frequently aligned) with broken orbitoids, bryozoans, echinoderms, rhodoliths and corals.

The lowest limestone lens, which was around 500m in lateral extent and not more than 30m thick, is exposed in blocks in a dry stream. This is the lens referred to by Pamouktchiev as "Middle Maastrichtian". On the other side of the track are blocks of freshly quarried limestone from a lens which must be stratigraphically higher and containing pieces of *Joufia* and *Pironaea* . The beds which Pamouktchiev calls "Upper Maastrichtian" and in which he has found many specimens of *Pironaea* are near the top of the hillside about 100m stratigraphically above the lowest lens. The locality is in thick pine forest and we did not manage to relocate it!

The lower part of the sequence at Yaroslavtzi comprises pebbly sandstones with some harder calcareous interbeds, each couplet being around 40cm thick. This is the type locality of the "caprinid" *Mitrocaprina bulgarica* Tzankov. The lower part of the sequence can also be found on a small hill, about 200m south of the main outcrop. This exposes ochre-coloured, limonitic, calcareous sandstone with orbitoids, gastropods, corals and other bivalves (*Glauconia, Venus* and small pectinids). In places, the orbitoids weather out of the sandstone and the gastropods and corals are preserved as moulds. The upper part of the Yaroslavtzi sequence is of an alternation of soft clayey sandstones with harder beds of sparitic limestone. Radiolitid and hippuritid rudists, some in life position, are abundant in the clayey beds, where they weather out. The limestone interbeds contain rudist fragments, oysters, orbitoids (both frequently covered by a micritic coating), corals and gastropods.

The environment represented by these deposits seems to have been at the foot of a delta. At Garlo the rudists are in isolated patches of fairly pure limestone together with other fauna which suggest fairly open marine conditions. At Yaroslavtzi the environment must have been slightly quieter water and more muddy.

The Yambol outcrop consists of an exposure of lavas which are overlain by highly altered orbitoid and coral limestones and then by less altered rudist and coral limestones, the latter not exposed *in situ* but found as loose blocks. The altered limestone contains a very well preserved and rich assemblage of orbitoids together with rotaline foraminifera and bryozoa. The loose limestone blocks show a wide range of lithologies including a diverse fauna of corals, solitary and colonial and some rudists (although these are by means numerous). The sediment varies from micrite (with the corals and hydrozoans) to a biomicrite grainstone with shelly fragments.

2.4.3 Romania

The Romanian worker Denise Lupu (eg. Lupu & Lupu, 1981; Lupu, 1984 and several other works cited in Sanchez, 1981) and her predecessor Dan Patrulius (Patrulius, 1974) have described Senonian rudist beds in central Romania. Most of the outcrop is in isolated basins in the northern Apuseni Mountains in west central Romania but there are also some from the Carpathians (Lupu, 1971). The Senonian [Coniacian-Maastrichtian] strata of this area are described as being of "Gosau facies". The deposits are rudist limestones, inoceramid and ammonite marls and some coal-bearing strata deposited in a littoral environment. These deposits are generally transgressive over older strata and are themselves covered by hemipelagic, sometimes "flyschoid" sediments. In the Borod Basin (see fig. 2/24i taken from Lupu, 1984) the uppermost of three rudist levels is pertinent to this discussion. The lithology is a yellow, sandy limestone and there are rudists and orbtitoids. This level is also exposed in the Remeti Basin (fig. 2/24ii). Campanian rudists are described from rocks of the Rosia Basin.

2.4.4 Austria, Hungary and Czechoslovakia

Lupu (1976) notes a locality in the Slovakian Carpathians, Czechoslovakia from which she describes two specimens. The Slovakian locality is at Šumiac in the upper Hron valley but the only details of the lithology available are that there are some planktonic foraminifera in the sediment surrounding the fossils.

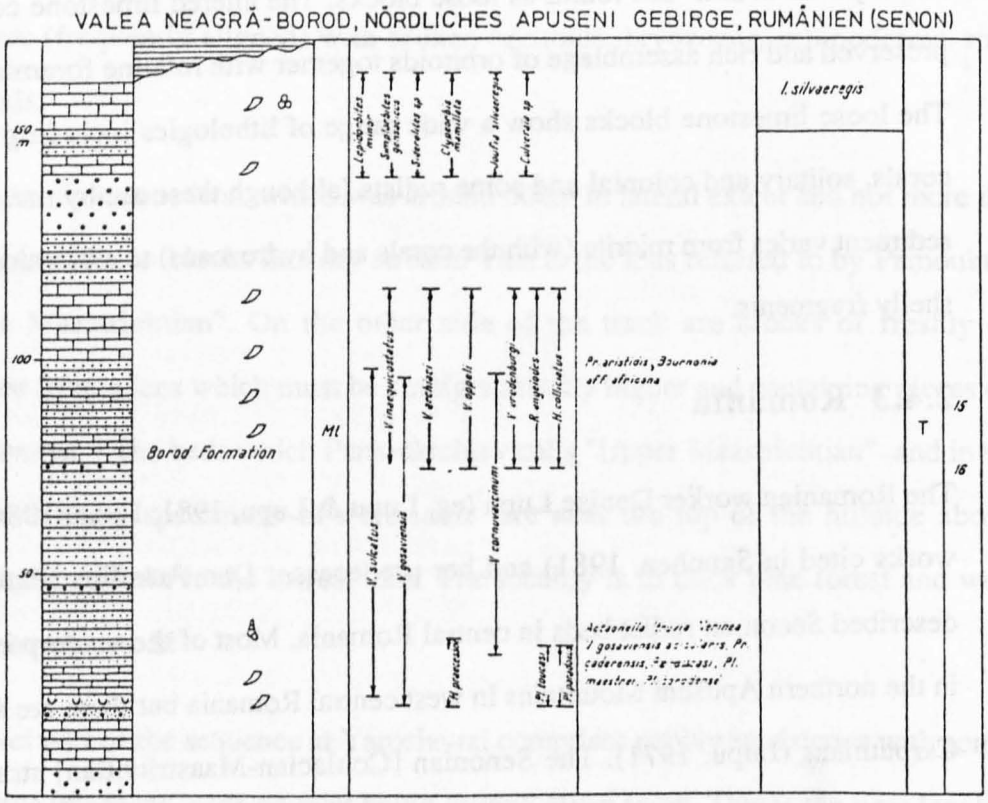


Fig. 6

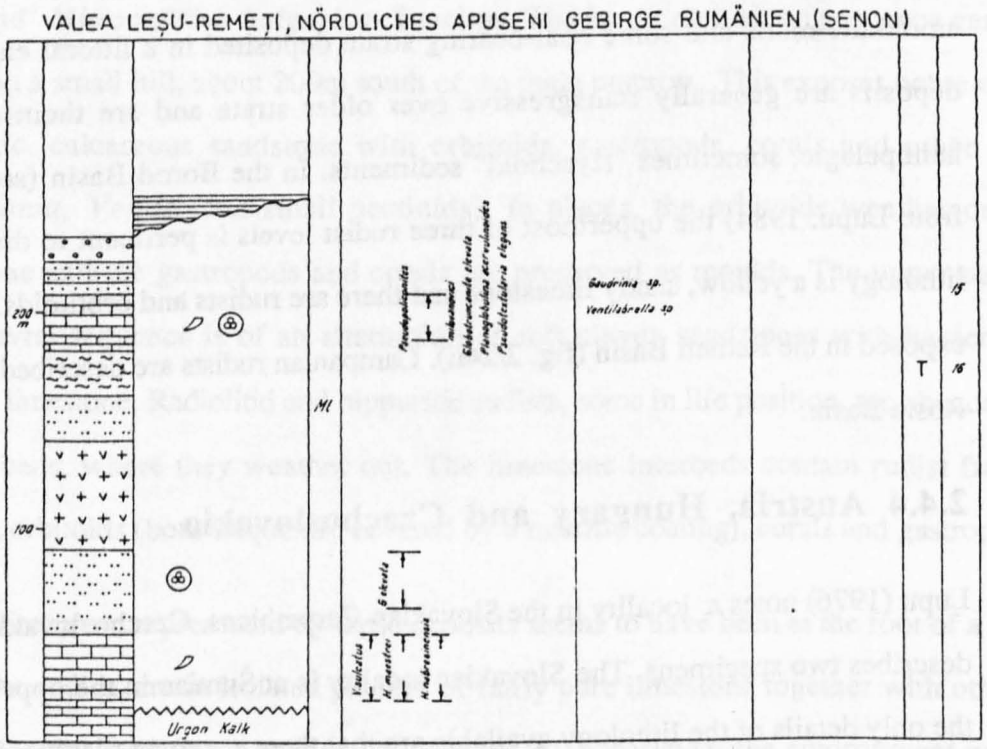


Figure 2/24. Stratigraphic sequences in i) the Borod Basin and ii) the Remeti Basin of the northern Apuseni Mountains, Romania

Information about the Hungarian fauna is restricted to an abstract by L. Czabalay of Budapest. She mentions Campanian rudists from the Dédestapolcsány region and three rudist zones from the Balkony Mountain the upper two of which are Upper Campanian - Lower Maastrichtian.

2.5. Middle Eastern Region: Turkey, Iran, Iraq, Lebanon, Israel, Syria

2.5.0 Introduction

There are undoubtedly rich Campanian-Maastrichtain rudist deposits in these areas but few details of the stratigraphy of the sequences are available to me. Locations of the localities are shown in figure 2/25 The grouping is quite heterogeneous with respect to the palaeogeography of Tethys at the end of the Cretaceous. The junction between north and south Tethys probably ran through what is now Turkey, Iran and Afghanistan so that there are deposits of both margins in this section.

2.5.1 Turkey

The rudist fauna of Turkey has been described in the works of Johannes Böhm (Böhm, 1927 cit. Kühn, 1933) and Othmar Kühn (Kühn, 1933) in the interwar years and more recently by Necdet Karacabey (Karacabey 1968, 69, 70, Karacabey-Öztemür 74, 76, 80, 81a & b,). There is also the work of Cox, 1960 and references to several other smaller works therein. Unfortunately all of these works describe collections without reference to the stratigraphic level and dating the unit according to the range of the rudists elsewhere.

Böhm's work was on rudists from Bithynia which is a former name for the north-western part of Turkey. Karacabey describes rudists from several localities in the Malatya region of central southern Turkey. The *Dictyopychus* specimens are from south-eastern Turkey.

2.5.2 Southern USSR, Iran & Afghanistan

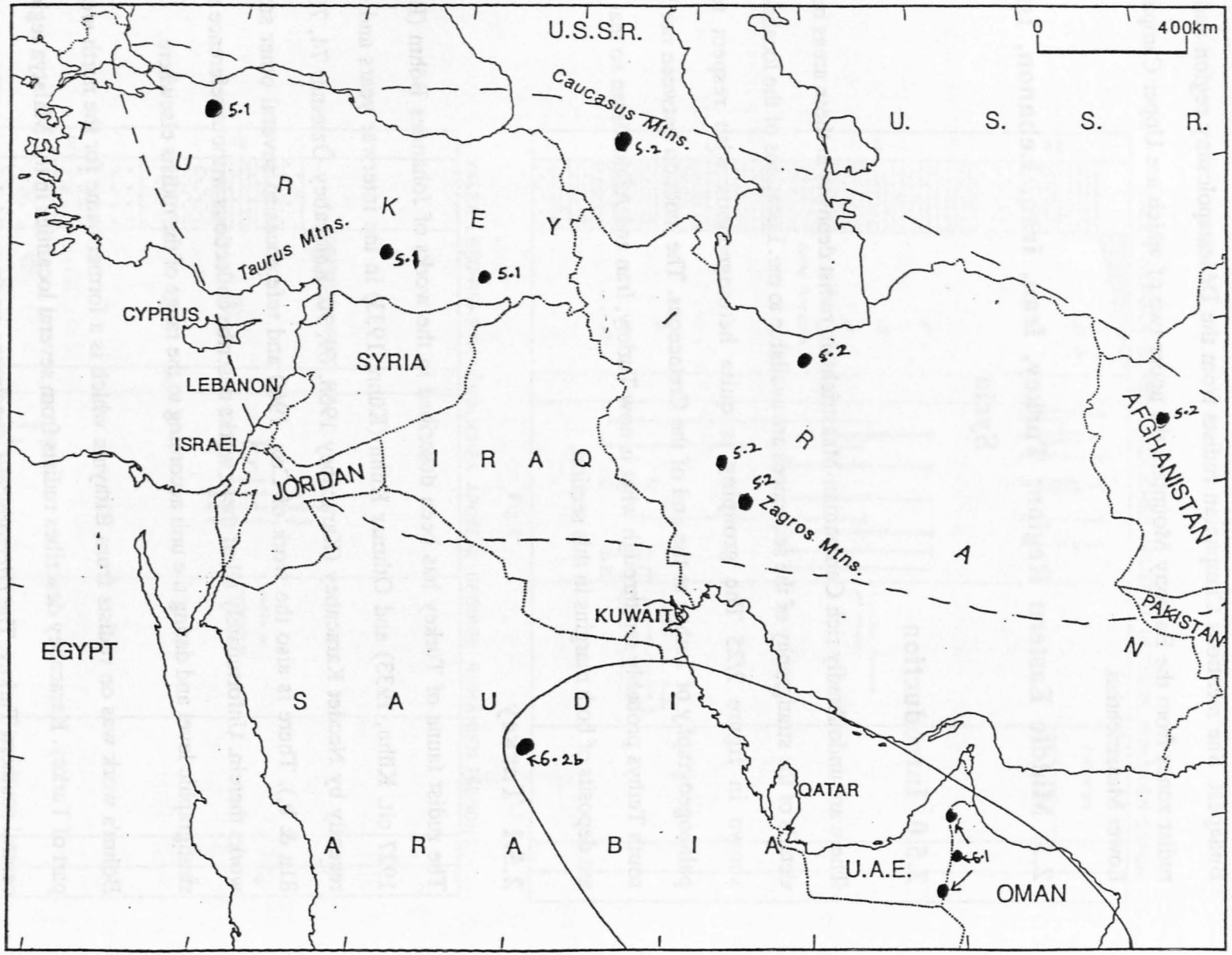


Figure 2/25. Map of the present day geography of the Middle East and surrounding areas showing the location of outcrops of Campanian-Maastrichtian rudist strata.

There are many records of Upper Cretaceous rudist localities in Iran, yet available (non-oil-company), coherent stratigraphic information is not so abundant and is mainly restricted to the results of early exploration in the early part of this century. Two relevant localities in the Zagros Mountains of southern Iran were recorded by Douvillé (1904). The first is in the Bakhtiari region, described as on the left bank of the Karun between Do-poulân and Djelil. The rocks are an interbedding of compact limestones with rudists and hard marls which contain the giant foraminifer *Loftusia* at the top. The second locality is in the Louristan area at the Kellapstun Pass, near Du Pulun. The beds are part of an anticline with 'Lower Cretaceous' in the core, no 'Middle Cretaceous', but a highly fossiliferous 'Upper Cretaceous' at the top. Two units are relevant to this work, Douvillé's *"Couches à Oursins"* or *"Couches à échinides"* and the overlying *"Couches à Cérites"* . The first is, as its name suggests rich in echinoids. The latter, the couches à Cérites is subdivided into two, the lower unit (called M3) consisting of green clays with some sandstone beds, limestone nodules and limestone beds. This unit is rich in fossils such as crustaceans, gastropods, bivalves, bryozoa and corals with rare echinoids. Overlying this is an alternation of yellow and black clays with numerous fossils, including small corals and echinoids (called M4 by Douvillé).

In the 1930's Othmar Kühn visited Iran and Afghanistan and collected specimens of what he was to call *Osculigera* , which is an eastern Tethyan relation of *Lapeirouseia*. Vogel (1971 - cit. Sanchez, 1981) reported rudists from west and north Afghanistan.

There are known to be rudists in southern USSR in Turkestan, the Crimea, the Caucasus and the Soviet Carpathians yet the only information available to me is an abstract by Yanin (1988).

2.5.3 Iraq, Syria, Lebanon, Israel, Jordan

Again I have no stratigraphical information about Campanian-Maastrichtian rudist localities from these areas, although they are mentioned in several older works which discuss the rudists (eg. Douvillé, 1910). One genus later to be called *Vautrinia* (Milovanovic, 1938), which has important palaeobiogeographic implications was collected by Vautrin from Syria .

2.6. Arabian Region: Oman, U.A.E.

2.6.0 Introduction

Rudist carbonates were formed in the shallow waters around the ophiolitic slice thrust onto the side of the Arabian continent in the Late Cretaceous. The ophiolitic complex, or Semail Nappe now forms much of the Oman Mountains and the shallow water sequences deposited on top are exposed in isolated rocky outliers or Jebels around the mountain chain both in the United Arab Emirates and in northern Oman.

To the west of the Oman Mountains crustal downwarping due to the weight of the ophiolite, caused the creation of a major basin, the Aruma Basin where pelagic sediments accumulated. Shallow-water sediments from the edge of the Aruma Basin occur to the south, in southern Oman and on the western side, to the east of the Arabian shield, in central Saudi Arabia. Locations of the rudist localities are shown in figure 2/25.

2.6.1 Oman Mountains

Skelton *et al.* (1990) describe several sections from the northern Oman Mountains (see fig. 2/26 & 27, the latter taken from Skelton *et al.*, 1990) and this account concentrates on those in the north, in the Qarn Murrah and Jebel Faiyah areas. The sequences are broadly similar throughout the region, demonstrating a sustained marine transgression and deepening, a trend terminated by possible emergence near the end of the Maastrichtian and then rapid subsidence in the Tertiary. The first sediments are laid down on top of the altered ophiolite, or thrusted sediments, with marked angular unconformity. Known as the Qahlah Formation, they comprise a few metres of conglomerate with some thin sandstone beds and represent a marginal to shallow marine environment. In the Jebel Faiyah area, where rudist fragments are common there are also some unworn, articulated specimens of *Durania* to be found amongst the boulders of the Qahlah Fm. These seem to be in life position and so presumably inhabited the foreshore zone.

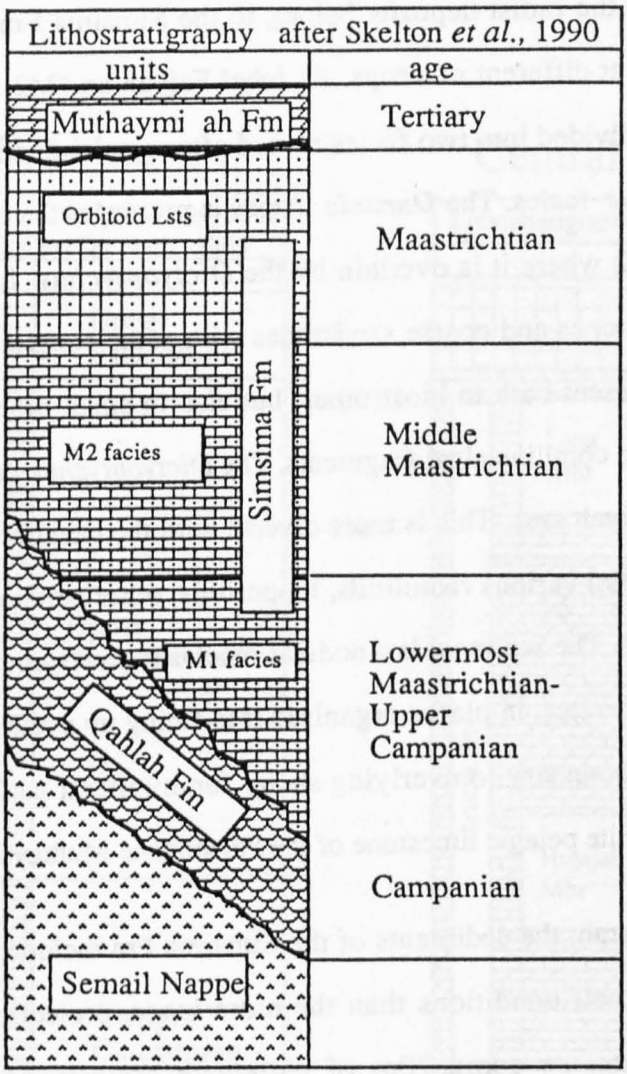


Figure 2/26

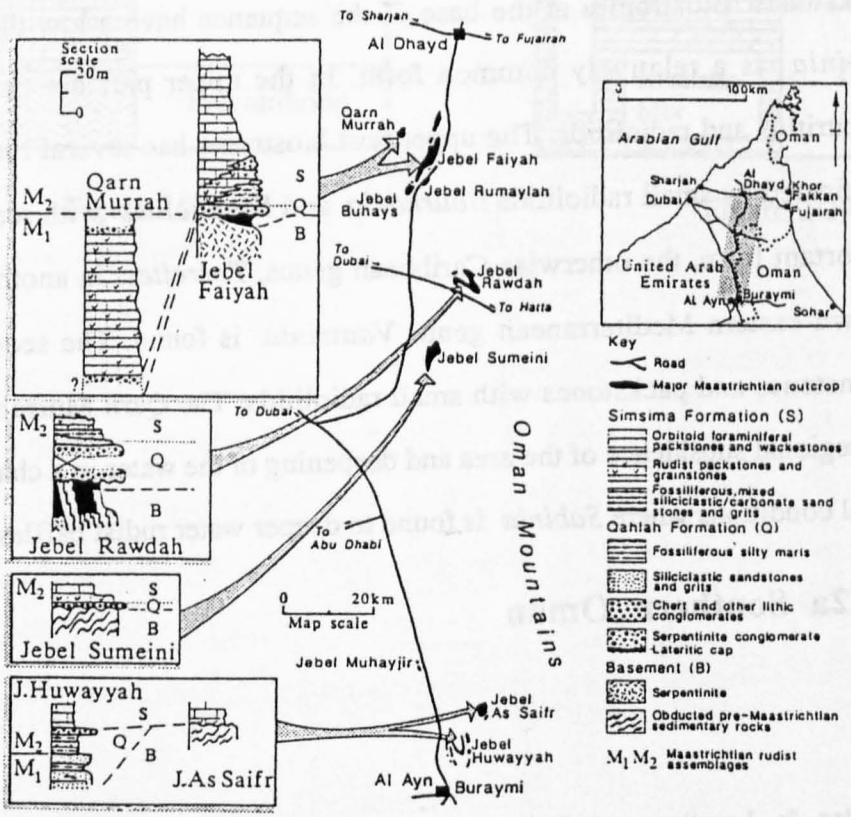


Figure 2/27. Relationship between the M1 & M2 facies at different outcrops around the Oman Mountains. From Skelton *et al.*, 1990.

The rest of the rudist deposits belong to the Simsima Fm and two distinct facies can be recognised at different outcrops. At Jebel Faiyah an "M2 fauna" is found and this can be further subdivided into two facies named after the dominant rudist species, a *Durania* and *Dictoptychus* facies. The *Durania* facies is present at the base of the sequence in northern Jebel Faiyah where it is overlain by the *Dictyoptychus* facies. The sediments are sandy rudist limestones and coarse sandstones with some conglomerate. *Durania* , the dominant rudist, is present both in biostromes, but also in small bioherms. The facies also includes orbitoids and coralline algal fragments. The *Dictyoptychus* facies is present in all sections in the Jebel Faiyah area. This is more diverse with the canaliculate *Dictyoptychus* (an eastern Tethyan rudist) various radiolitids, hippuritids, other epifaunal bivalves, gastropods, corals and orbitoids. The sediment is a nodular bioclastic packstone with some sporadic sandstones and conglomerates, in places organised into fining up cycles a few metres thick. There is a gradational boundary to overlying shelly foraminiferal packstones, then an unconformity before the white pelagic limestone of the Palaeogene Muthaymimah Fm.

At Qarn Murrah, the sediments of the Simsima Fm include the M1 fauna. This represents more open shelf conditions than the more inner, protected shelf environments at Jebel Faiyah. There are some 70m of carbonate grainstones and rudist-coral biostromal packstones. Biostromes at the base of the sequence have a low diversity of rudists, and *Sabinia* is a relatively common form. In the upper part are rudist bafflestones with hippuritids and radiolitids. The uppermost biostrome has several rudist assemblages - one dominated by small radiolitids *Bournonia* and *Biradiolites* with scarce hippuritids and an important form, the otherwise Caribbean genus, *Torreites*. In another biostrome the little known eastern Mediterranean genus *Vautrinia* is found. The sequence terminates with grainstones and packstones with small radiolitids. The Qarn Murrah sequence also shows the regional subsidence of the area and deepening of the water in a change from well-washed shoal conditions where *Sabinia* is found to deeper water rudist bafflestones.

2.6.2a Southern Oman

S. Oman

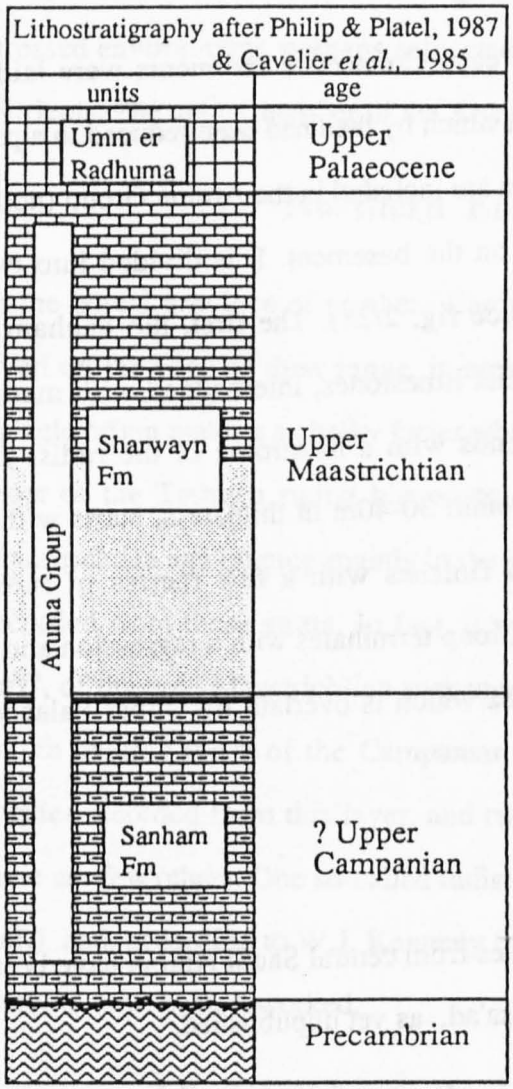


Figure 2/28

Central Saudi Arabia

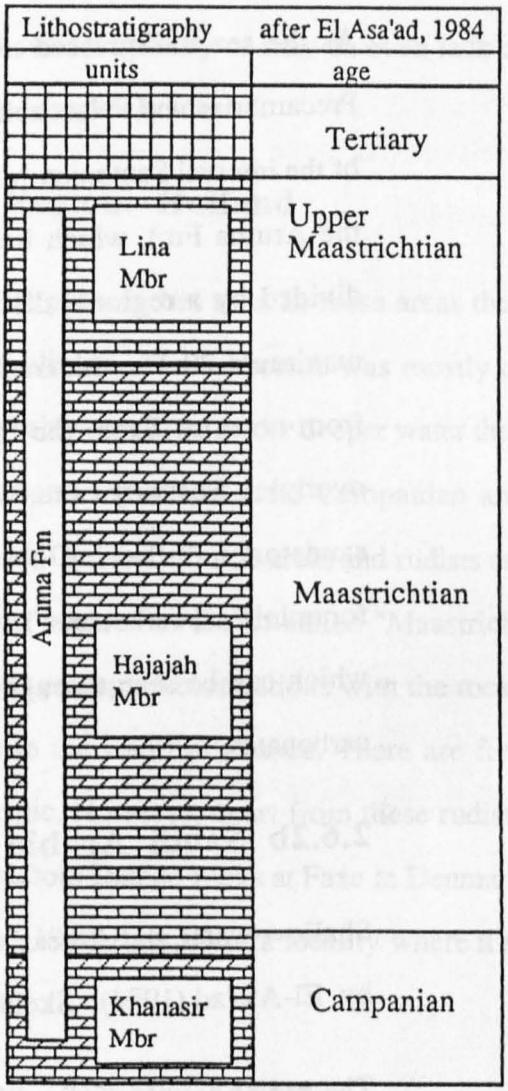


Figure 2/29

Rudist carbonates from the Late Cretaceous were discovered in the Dhofar region of south-west Oman when the area was mapped. The stratigraphy was briefly summarised in Cavelier *et al.*, 1985, and the fauna in Philip & Platel, 1987.

As the sea transgressed towards the east, Cretaceous sediments were laid down upon a Precambrian and Palaeozoic basement which by then had been reduced to a peneplain. Strata of the interval Santonian-Maastrichtian are included in the Aruma Group (nothing to do with the Aruma Fm), which lies directly on the basement. It is divided into two formations, divided by a regional discordance (see fig. 2/28). The first, the Sanham Fm reaches a maximum 20m in thickness with rudist limestones, interbedded with marls. In a section from north of Sadh, the formation ends with a biostrome of the rudist *Torreites*. The overlying Sharwayn Fm, which is around 30-40m in thickness, starts with cross-bedded sandstones, following by marls and finishes with a few metres of rudist and larger foraminiferal carbonate. The Aruma Group terminates with a regression and unconformity which can be seen throughout the area which is overlain by Upper Palaeocene platform carbonates.

2.6.2b Saudi Arabia

Shallow-water, rudist-bearing carbonates from central Saudi Arabia have been investigated by El-Asa'ad (1984), Skelton & El-Asa'ad, as yet unpublished.

The rudist-bearing sediments of potential Late Campanian and Maastrichtian age are all included in the Aruma Fm which is split into three members (see fig. 2/29). Rudists are found at the top of the lowest member, the Khanasir Limestone Mbr and in the middle, Hajajah Limestone Mbr in around 85m of strata. These rocks are mostly nodular limestones with *Thalassinoides* burrows and some dolomitization. They represent shallow, mostly subtidal environments cut by channels. Rudists are present in certain, discrete beds, mostly as biostromes, but there are also some bioherms. They are generally low in diversity and some beds are even bi- or mono-specific. One particularly notable bed, at the top of the Khanasir Limestone Mbr extends laterally for tens or even hundreds of kilometres contained

specimens of *Durania* in life position. Sometimes the same bed grades into different monospecific assemblages and, interestingly, there are no hippuritids. A new genus of caniculate rudist, similar to *Dictyoptychus* is to be described from this level. Skelton interprets the fauna as representing opportunistic (presumably rapid) colonisation of a stressed environment, perhaps subjected to heat, excessive salinity or may be even lack of nutrients. The upper member of the Aruma Fm is the Lina Shale Mbr.

2.7 Northern European Region: Holland

In the boreal province of northern Europe rudists are present, but rare. In these areas they lived on the edge of their range, in areas of cooler climate. The carbonate was mostly of pelagic origin making a chalky facies which was probably deposited under deeper water than most of the Tethyan rudist bioconstructions. Carbonate rocks of Late Campanian and Maastrichtian age outcrop mainly in the Danish - north German - Dutch areas and rudists are recorded from these strata. In fact, it was the rudist horizon in the so-called "Maastricht tuff", of the type Maastrichtian sequence, which first prompted correlations with the rocks which overlay those of the Campanian stratotype in the south of France. There are five species recorded from this layer, and two are endemic. However, apart from these rudists there are few others. One so-called rudist is recorded from Danian rocks at Faxe in Denmark (ref.) and, according to W.J. Kennedy (pers. comm., 1990), this is not a locality where it is likely to have been reworked.

2.8. Caribbean Region: Cuba, Jamaica, Mexico

In the Caribbean rudists are known from Cuba, Jamaica, Puerto Rico, the lesser Antilles (Chubb, 1956) as well as localities in Mexico and Guatemala (Sanchez, 1981). At the end of the Cretaceous the Caribbean was an active plate margin and many of these areas of carbonate platform which had formed on island arcs above the subduction zone. The sedimentary sequences therefore consist mostly of clastic and volcaniclastic lithologies with only minor carbonate. According to Kauffman & Johnson (cited as "in press" in Hut *et al.*, 1987), the carbonate facies was still present in the Palaeocene. As discussed in the introduction, from the Aptian onwards, the Caribbean had become progressively more

distinct as a separate palaeobiogeographic province. For this reason a detailed discussion of the faunas and facies is outside the scope of this work.

Chapter 3: Rudist occurrences

This chapter includes tables of the cited occurrences of purported Upper Campanian and Maastrichtian rudist species from the various geographical areas. The tables are compiled using mostly recent review articles rather than original sources with the more recent source given priority because of potentially increased understanding of fauna. In the time available the lists can not hope to be complete and it is mainly the older records of isolated occurrences of rudists in areas of which the fauna has been reviewed recently, which are missing. In my opinion this not a significant omission as the inclusion of these records can give a misleading view of the diversity of a particular region. In the larger studies several forms belonging to the same species can be assessed together and the intraspecific variation estimated. Many of those isolated examples in fact belong to species described later by authors working in the same area but by using new names (and without completing synonomy lists). For areas which have not been investigated recently, older sources (which also do not generally give many details of stratigraphy) have had to be used but as many of the original papers are not available to me I have in some instances had to use the compilation of hippuritids and radiolitids of Sanchez, 1981. As this work does not seek to assess the validity of the purported records it is considered of less importance than other reviews.

Minor amendments have been made to the lists, most of which are spelling mistakes and further corrections to the taxonomy are limited to the following: Firstly, where some particularly old sources have been used and the fossil name has since been changed, the new name is adopted and the cited one placed in square brackets. Most of these changes are restricted to changes in the genus and the new genus name is that given in Sanchez, 1981. Secondly, where an identification has only been to genus, and there are other examples of this genus in the same unit which have been identified to species level, the form is not included (unless very few species are known from a particular genus). Thirdly, several workers have been using the names *Vaccinites, Hippuritella* and sometimes *Orbignya* as subgenera of the genus *Hippurites* but as I believe this to be incorrect, I will use *Vaccinites* and *Hippuritella* and *Hippurites* as genus names.*Vaccinites* was originally introduced as a

genus (Fischer, 1887, sit. Sanchez, 1981) in its own right and *Hippuritella* , though previously in use as a subspecies, was made a full genus by Douvillé, 1908 (cit. Sanchez, 1981). The name *Orbignya* was used incorrectly by Toucas as it is merely a junior synonym of *Hippurites* . In the conclusions at the end of this chapter I will comment on the validity of the quoted species and I will make some informal recommendations for alterations in the taxonomy in order to compare the diversity between the different areas.

3.1 Pyrenean Region

Table of rudists from areas 1.1ai, French Prepyrenees & 1.1b, Pedraforca area
from Bilotte, 1985.

	Ca3	Ca4	Ma1	Ma2a	Ma2b
Hippuritids					
Hippuritella castroi (Vidal)					x
Hippuritella lapeirousei (Goldfuss)				x	x
Hippurites aff. agustinensis (Ciry)			x	x	x
Hippurites lamarcki Bayle			x	x	x
Hippurites radiosus et var. Des Moulins			x	x	x
Radiolitids					
Biradiolites (?) similivalvis Astre (?)				x	*
Praeradiolites boucheroni (Bayle)			x	x	x
Praeradiolites echennensis Astre	(x)	(x)	x	x	x
Praeradiolites leymeriei (Bayle)				x	x
Praeradiolites maximus Astre				x	x
Radiolites cf. albonensis Toucas				x	*
Radiolites alsinianus Astre				x	*
Radiolites aurigerensis Munier-Chalmas	(x)	(x)	x	*	
Radiolites jovis Astre				x	*
Radiolites nouleti (Bayle)	(x)	(x)	x	*	
Radiolites sellesi Baudelot					x
Others					
Monopleura moroi (Vidal)					x*1
Apricardia toucasiana D'Orbigny	?	?	x	x	*
Apricardia sicoris Astre		?	x	x	*

* = may range just into this zone
*1 Bilotte, pers. comm.

Table of rudists from areas 1.1aii & 1.1b, Spanish Pyrenees
from: Pascual et al., 1987, (1); Pons, 1982 (2); Pons & Vicens, pers. comm., 1987 (3)

	Montsech			*S.M&TB		Cat.		
	Ca3	Ma1	Ma2	Ca	Ma	Ca	Ma	Ref.
Hippuritids								
Hippuritella cf. bulgarica (Toula)						x	x	3
Hippuritella castroi (Vidal)			x		x		x	1, 2
Hippuritella lapeirousei (Goldfuss)		x			x		x	1, 2
Hippuritella sp. cf. heritschi Kühn						x	x	3
Hippuritella sulcatoides (Douvillé)						x		2
Hippuritella variabilis Munier-Chalmas	x					x		1, 2
Hippuritella sp.1						x		3
Hippuritella sp.2						x		3
Hippuritella sp.3							x	3
Hippurites bioculatus Lamarck				x				2
Hippurites heberti Munier-Chalmas						x*		2
Hippurites lamarcki Bayle							x	2
Hippurites radiosus Des Moulins					x		x	2
Hippurites serratus Douvillé				x			x?	2
Hippurites verneuilli Bayle						x		2
Hippurites vidali Matheron	x					x		1, 2
Vaccinites archiaci Munier-Chalmas	x					x		1, 2
Vaccinites latus major Toucas						x		2
Vaccinites loftusi Woodward						x	x	3
Vaccinites robustus Toucas						x		2
Vaccinites sulcatus (DeFrance)						x*		2
Radiolitids								
Agriopleura fumanyae (Vidal)							x	2
Agriopleura garumnica Alibert					x			2
Agriopleura ("Radiolites") moroi (Vidal)			x					1
Biradiolites aquitanicus Toucas				x	x			2
Biradiolites ara Pons			x					1
Biradiolites baylei Toucas					x			2
Biradiolites chaperi Bayle			x					1
Biradiolites collsensis Astre							x	2
Biradiolites lameracensis Toucas					x			2
Biradiolites leychertensis Toucas	x					x		1, 2
Biradiolites orbignyi Toucas	x					x		1, 2
Biradiolites osensis Vidal					x?			2
Biradiolites posae Vidal					x			2
Biradiolites royanus d'Orbigny							x	2
Biradiolites siracensis Toucas								3
Lapeirousia jouanneti (Des Moulins)						x		2
Lapeirousia sp. 1	x							1
Lapeirousia sp. 2		x						1
Lapeirousia sp. 3		x						1
"one-banded monster"		x						3
Praeradiolites aristidis Munier-Chalmas						x*		2
Praeradiolites balensis Astre						x		2
Praeradiolites boucheroni (Bayle)		x	x		x		x	1, 2
Praeradiolites hoeningshausi (Des Moulins)						x*		2
Praeradiolites leymeriei (Bayle)					x?			2
Praeradiolites maximus Astre							x	2
Praeradiolites subcoquandi Toucas						x		2
Praeradiolites subfuxeensis Astre						x		2
Praeradiolites subtoucasi Toucas	x					x		1, 2
Radiolitella pulchellus (Vidal)		x			x		x	1, 2

	Montsech Ca3	Ma1	Ma2	*S.M&TB Ca	Ma	Cat. Ca	Ma	Ref.
Radiolitella n. sp.					x			2
Radiolites alfredi Pons					x			2
Radiolites alsinanus Astre							x	2
Radiolites angeoides (Lapeirouse)						x		2
Radiolites aurigerensis Munier-Chalmas						x*		2
Radiolites nouletti (Bayle)	?x					x		2
Radiolites planicostatus (Vidal)							x	2
"Radiolites" sellesi Baudelot			x					1
Radiolites similivalvis Astre						x	x	2
Rosellia xavieri Pons					x			2
Others								
Apricardia sicoris Astre		x						1
Apricardia sp.	x							1
Mitrocaprina vidali	x							3
Mitrocaprina sp. 1	x							3
Mitrocaprina sp. 2		x						3
Monopleura moroi (Vidal)			x					1
Plagioptychus sp.	x							3
Rousselia guilhoti ?	x							3

x* suggests that this species may be predominantely from Lower Campanian strata given its occurrence in the Montsech sequences.

*S.M. & T.B.= Sierras Marginales and Tremp Basin

Table of rudists from area 1.2, Aquitaine, Southern France
from the Dordonian beds, as cited in: Bilotte, 1985 (1); Philip & Bilotte, 1985 (2); Freneix & Sornay, 1974 (3)

Hippuritids	
Hippuritella lapeirousei (Goldfuss)	1,2
Hippurites radiosus Kühn	1,2
Radiolitids	
Lapeirousia jouanneti (Des Moulins)	2
Praeradiolites cylindraceus (Des Moulins)	2
Radiolites acuticostatus ?	1
Biradiolites [Radiolites] ingens (Des Moulins)	1
Others	
Artigesia angulosa (d'Orbigny)	3

Table of rudists from area 1.3, Sardinia
from blocks in the Tertiary Conglomérat de Cuccuru 'e Flores, from Busulini *et al.*, 1984

	Camp. at Sovana	U. Maas. at Lanaitto
Hippuritids		
Hippuritella cornucopiae (Defrance)	x	
Hippuritella variabilis Munier-Chalmas	x	
Hippurites heberti Munier-Chalmas	x	
Hippurites heberti vidali (Matheron) Toucas	x	

3.2. Periadriatic Region

Table of rudists from area 2.1a, Southern Slovenia
from: Dolenja Vas, Drobne *et al.*, 1987 (1); Maastrichtian of Southern Slovenia, Pleničar & Pavlovec, 1981 (2); Pleničar, 1979 (3); 1977 (4); 1974 (5); 1973 (6) from M. Nanos only, Pleničar, pers. comm., 1987 (7); Trnovški Gozd/Goriška Brda, Bignot, 1972 (8)

	Main rudist Lst	Vreme beds	Ref.
Hippuritids			
Hippuritella [Hippurites] castroi (Vidal)	x		2
Hippurites heritschi Kühn	x		2
Hippurites radiosus Des Moulins	x		2
Pironaea machnitschi Kühn	x		8
Vaccinites atheniensis Ktenas	x		3
Vaccinites braciensis Sladić-Trifunović	x		2,3
Vaccinites giordanii Pirona	x		2,3
Vaccinites ultimus Milovanović	x		2
Radiolitids			
Apulites giganteus Tavani	x		2,5
Biradiolites fissicostatus D'Orbigny	x		3
Biradiolites sp. 1	x		1
Biradiolites sp. 2		x	1
Bournonia baylei Toucas		x	1
Bournonia cf. dinarica Slišković	x		6
Bournonia parva Pejović		x	1
Bournonia problematica Drobne et al.		x	1
Bournonia aff. quadripinnae Pejović		x	1
Bournonia aff. retrolata Astre		x	1
Bournonia triangulata Drobne et al.		x	1
Bournonia cf. wiontzeki Pejović		x	1
Bournonia adriatica Pejović	x	x	1
Bournonia judaica Blanckenhorn	x	x	1
Colveraia variabilis Klinghardt	x		7
Fossulites undesaltus Astre	x		1
Katzeria hercegovinaensis Slišković	x		2,6
Kuehnia aff. serbica Milovanović	x		1
Joufia reticulata Böhm	x		7,8
Pseudopolyconites cf. balcanicus Milovanović & Sladić	x		4
Pseudopolyconites cf. ovalis Milovanović	x		4
Pseudopolyconites lascarevi Milovanović & Sladić	x		4
Pseudopolyconites sp.	x		1
Praeradiolites boucheroni strobilus Tavani	x		5
Radiolitella cf. forojuliensis Pirona	x		5
Radiolitella maestrichtiana Pejovic	x		2
Radiolitella sp.	x	x	1
Others			
Gyropleura		x	1, 3
Sabinia slovenica Plenićar	x		3, 4
Sabinia sp. div.	x		3, 4

Table of rudists from area 2.1b, Croatia
from: Brac Island, Pejović & Radoičić, 1987 (1) & from Hvar Island Sladić-Trifunović, 1980 (2); Polšak & Mamuzić, 1969 (3); Slišković, 1971, 1970 cit. Sanchez, 1981 (4)

	Cz 6	Cz 7	P. Fm	V. Fm	B. Fm	Ref.
Hippuritids						
Hippuritella cornucopiae Defrance	x					3
Hippuritella [Hippurites] lapeirousei (Goldfuss)	x	x				3
Hippuritella maestrei Vidal	x	x				3
Hippuritella variabilis Munier-Chalmas	x	x				3
Hippurites bioculatus Lamarck				x		1
Hippuritella [Hippurites] colliciatus (Woodward)	x	x	x	x		1, 2,3
Hippuritella [Hippurites] castroi (Vidal)	x	x				3
Hippurites heritschi Kühn	x	x	x cf.	x		2, 3
Hippurites matheroni aff. montsecana (Vidal)				x		1
Pironaea polystyla milovanovici Kühn		x	x			2, 3
Vaccinites atheniensis Ktenas				x		1
Vaccinites braciensis Sladić-Trifunović	x	x		x		1, 3
Vaccinites conicus adriaticus Sladić-Trifunović			x			1
Vaccinites loftusi Woodward	x		x	x		1,2, 3
Vaccinites sulcatissimus (Douvillé)				x		1
Vaccinites sulcatus Defrance	x					3
Vaccinites vesiculosus Woodward				x		1
Vaccinites ultimus Milovanović		x	x			1, 3
Vaccinites sp.					x	1
Radiolitids						
Apulites giganteus Tavani						4
Apulites lublanensis Slišković						4
Biradiolites lumbricoides Douvillé			x			1
Bournonia adriatica Pejović				x	x	1
Bournonia bournoni Des Moulins					x	1
Bournonia dinarica Slišković						4
Bournonia excavata (d'Orbigny)	x	x	x cf.	x		1, 3
Bournonia fourtaui Douvillé			x		x	1
Bournonia wiontzeki Pejović				x		1
Colveraia variabilis Klinghardt			x			1, 2
Distefanella cf. radoicicae Pejović					x	1
Durania austinensis (Roemer)		x				3
Fundinia biscopulata Sladić-Trifunović & Pejović				x		1
Gorjanovicia acuticostata Polšak			x	x		1
Joufia reticulata Böhm			x			1, 2
Katzeria hercegovinaensis Slišković			x			1, 4
Lapeirousia crateriformis					x	1
Lapeirousia orientalis					x	1
Lapeirousia zitteli Douvillé	x					3
Lapeirousia sp.			x			1
Lapeirousia sp.				x		1
Medeella sp.			x			1
Milovanovicia sp.			x			1
Petkovicia verajana Slišković		x				3, 4
Praeradiolites boucheroni (Bayle)	x		x		x	1, 3
Praeradiolites cylindraceus (Des Moulins)	x					3
Praeradiolites leymeriei (Bayle)	x					3
Pseudopolyconites campobassoi			x			1, 2
Pseudopolyconites laskarevi Milovanović-Sladič			x			1
Pseudopolyconites sp.				x		1
	Cz 6	Cz 7	P. Fm	V. Fm	B. Fm	Ref.

Pseudopolyconites sp.				x	1
Radiolitella maestrichtiana Pejović &				x	1
Radiolites angeoides (Lapeirouse)			x	x	1
Radiolites nouleti (Bayle)				x	1
Radiolites squamosus d'Orbigny				x	1
Radiolites subangeiodes Toucas	x				3
Rajka pejovicae Milovanović			x	x	1
Rajka spinosa Milovanović		x	x	x	1, 3
Others					
Sabinia sp.			x		1
Plagioptychus sp.				x	1
Plagioptychus sp.				x	1
Gyropleura sp.				x	1

Cz = Cenozone.
P Fm = Pucisca Formation
V Fm = Vocisca Formation
B Fm = Brac Formation

Table of rudists from area 2.2a, Northern Italy
from M. Jouf: Swinburne & Noacco (in press) (1); Klinghardt, 1921 (2).

---

	top Unit 2	Unit 3	Unit 4	*K.Q.	Ref.
Hippuritids					
Hippuritella [Hippurites] lapeirousei (Goldfuss)			x		1
Pironaea polystyla forojuliensis Klinghardt			x	x	1, 2
Vaccinites [Hippurites] giordani (Pirona)				x	2
Radiolitids					
Biradiolites carezi Toucas				x	2
Biradiolites coquandi Toucas				x	2
Biradiolites ingens Des Moulins				x	2
Biradiolites royanus (d'Orbigny)				x	2
Biradiolites sp. 1	x				1
Biradiolites stoppani (Pirona)				x	2
Bournonia excavata (d'Orbigny)		x			1
Radiolites pseudomonopleura Klinghardt	x			x	1, 2
Colveraia variabilis Klinghardt			x	x	1, 2
Joufia reticulata Böhm			x	x	1, 2
Katzeria sp	x		x		1
Medeella sp.	x				1
Praeradiolites crassissimus Klinghardt				x	2
Praeradiolites hoeningshausi (Des Moulins)				x	2
Praeradiolites riberacensis Toucas				x	2
Praeradiolites sinuatus d'Orbigny					2
Praeradiolites sp.			x		1
Pseudopolyconites sp. 1		x			1
Pseudopolyconites sp. 2			x		1
Radiolitella forojuliensis Pirona				x	2
Radiolites angeoides (Lapeirouse)				x	2
Radiolites macrodon Pirona				x	2
Radiolites [Sphaerulites] mamillaris Matheron				x	2
Radiolites musculosus Klinghardt				x	2
Radiolites sp.			x		1
Radiolites [pasani] pasinianus Pirona				x	2
Radiolites radiosus d'Orbigny				x	2
	top Unit 2	Unit 3	Unit 4	*K.Q.	Ref.

Radiolites squamosus d'Orbigny		x	2
Radiolites styriacus (Zittel)		x	2
Rajka spinosa	x		1
Sauvagesia sp.	x		1
Lapeirousia [Sphaerulites] crateriformis (Des Moulins)		x	2
Others			
Apricardia cf. pironai (Böhm)		x	2
Apricardia sp.	x		1
Plagioptychus sp.	x		1
Sabinia anienis Parona	x	x	1, 2

*K.Q.= Klinghardt's Quarry, the location of which is described in Swinburne & Noacco and rudists come from from stratigraphic units 2, 3, & 4

Table of rudists from areas 2.3a & 2.3b Murges and Gargano, Southern Italy.
Murges from: Laviano, 1984 (1); Laviano, 1985 (2); Campobasso, 1972 (3). Gargano from Borgomano & Philip, 1987 (4)

	C. di Alt.*1	Caraca Fm*2			
		UC	LM	UM	Ref.
Hippuritids					
Hippuritella [Hippurites] colliciatus (Woodward)			x	x	4
Hippurites heritschi Kühn	x		x	x	2, 4
Pironaea praeslavonica Milovanović et al.			x		4
Radiolitids					
Kurtinia hemisphaerica			x		4
Joufia cf. reticulata Böhm	x	x	x	x	1, 4
Radiolites angeoides Lamarck	*3				3
Others					
Mitrocaprina sp.	x				1
Sabinia cf. anienis Parona	x	x	x	x	1, 4
Sabinia sp.			x	x	4

*1 Laviano's rudists are from the top of the Calcari di Altamura in that portion considered U. Camp.-Maas.

*2 Borgomano & Philip's rudists are from their Upper Campanian, Lower Maastrichtian and Upper Maastrichtian subdivisions but see table for exact ranges.

*3 Campobasso's "Senonian" form is included.

Table of rudists from area 2.3c, Salento
from: Cestari & Sirna, 1987 (1); Sladić-Trifunović & Campobasso, 1980 (2); Campobasso & Morolla, 1975 (3)

	U. Camp.		U. Maas.		Ref.
		L. Maas.		C-M undiv	
Hippuritids					
Hippuritella [Hippurites] colliciatus (Woodward)	x	x	x	x	1,2
Pironaea polystyla slavonica Hilber		x	x		1,3
Vaccinites ultimus Milovanović			x		1

Radiolitids

	U. Camp.	L. Maas.	U. Maas.	C-M undiv	Ref.
Bournonia excavata (D'Orbigny)	x	x	x		1
Bournonia hercegovinica Slišković			x		1
Bournonia wiontzeki Pejović		x	x		1
Durania sp.				x	3
Joufia reticulata Boehm		x	x		1
Klinghardtites [Radiolites] musculosus Klingthardt				x	2,3
Medeella zignana (Pirona)	x				1
Petkovicia verajana Slisković		x	x		1
Pseudokuehnia sp.				x	2
Pseudopolyconites ovalis apuliensis Sladić-Trif-Campobasso		x	x		1,2
Radiolitella maestrichtiana Slišković.		x	x		1
Radiolites angeoides (De Lapeirouse)	x	x	x		1
Radiolites spongicola Astre	x	x	x		1
Radiolites styriacus (Zittel)				x	2
Rajka spinosa Milovanović		x	x		1
Sauvagesia sp.				x	2,3
Others					
Sabinia cf. anienis		x	x	1	
Mitrocaprina bulgarica Tzankov		x	x	1	
Apricardia pachiniana Sirna	x	x	x	1	

Table of rudists from area 2.3d, Ionian Islands
from Accordi et al., 1987

Hippuritids
Hippuritella [Hippurites] colliciatus (Woodward)
Hippuritella [Hippurites] lapeirousei (Goldfuss)
Hippurites heritschi Kühn
Hippurites socialis Douvillé
Radiolitids
Biradiolites angulosus D'Orbigny *
Biradiolites angulosissimus Toucas *
Radiolites angeoides (De Lapeirouse)
Radiolitella maestrichtiana Slišković
Durania apula Parona
Joufia reticulata Böhm
Rajka spinosa Milovanović
Pseudopolyconites ovalis apuliensis Sladić-Campobasso
Lapeirousia sp.
Lapeirousia zitteli Douvillé *
Bournonia wiontzeki Pejović
Sauvagesia sp.
Others
Mitrocaprina bulgarica Tzankov
Sabinia anienis Parona

* = from inner shelf facies with no obvious indicators of age. similar beds in Salento are assigned to the Upper Campanian

---

Table of rudists from area 2.4 Latium-Abruzzi and Matese Platforms, Central Italy
from: the Senonian of M. Maiella, Accordi et al, 1988 (1); the Simbruini-Ernici & Lepini Mnts, Cestari & Sirna, 1988 (2)

	Ref.
Hippuritids	
Hippuritella	1
Hippurites	1
Pironaea	1
Vaccinites	1
Radiolitids	
Joufia	1
Milovanovicia	1
Pseudopolyconites	2
Radiolitella	1
Rajka	1
Sauvagesia	1
Radiolitids indet.	2
Others	
Apricardia	1
Sabinia	1

3.3 North African Region

Table of rudists from area 3.1, Southern Valencia Province, South East Spain
from: Nicolasa Quarry, Pons & Vicens, unpubl. 1988 (1); Quatretonda, Philip, 1985a (2)

	N.Q.	Quatretonda			Ref.
		Bast. Fm unit II	unitIII	Torr. Fm unit I	
Hippuritella cf.*lapeirousei* (Goldfuss)				x	2
Hippuritella [Hippurites] colliciatus (Woodward)	x				1
Hippurites heritschi Kühn	x				1
Hippurites cf. *radiosus* (Des Moulins)		x			2
Pironaea corrugata nicklesi Philip		x			2
Pironaea milovanovici Kühn	x				1
Pironaea milovanovici quatretondaensis Philip*		x			2
Pironaea polystyla Meneghini		x			2
Vaccinites aff. *loftusi* Woodward	x				1
Vaccinites ultimus Milovanović	x				1
Joufia sp.	x				1
Lapeirousia sp.	x				1
Sabinia sp.			x		2

specimens from the Nicolasa Quarry are all from the "Lower Maastrichtian"

Table of rudists from area 3.3, Sicily
from: Camoin, 1985 (1); Camoin *et al.*, 1983 (2); Sirna, 1983 (3); Matteucci *et al.*, 1982 (4)

	Pach-P.P.P-C.P*	Capo	Pass.Priolo	Ref.
Hippuritids				
Hippurites cornucopiae Defrance	x			2,4
Hippurites heritschi Kühn	x			2,4
Pironaea polystyla Meneghini	x			4
Vaccinites conicus adriaticus Sladić-Trifunović		x		2
Vaccinites cornuvaccinum Bronn	x			4
Vaccinites ultimus Milovanović		x		2
Hippuritids indet.			x	1
Radiolitids				
Biradiolites sp.	x			2
Durania sp.		x		2
Durania austinensis Parona	x			4
Eoradiolites sp.		x		2
Lapeirousia cf.*crateriformis* Milovanović	x			2
Lapeirousella cfr. *orientalis* Milovanović	x			4
Joufia reticulata Böhm	x	x	x	1,2,4
Neoradiolites serbicus Milovanović		x		2
Pseudopolyconites lascarevi Milovanović		x		2
Others				
Sabinia aniensis Parona	aff.	x	x	1,2,4
Sabinia sp.		x	x	1,2,4
Mitrocaprina sp.		x		2
Mitrocaprina bulgarica Tzankov		x		4
Plagioptychus sp.	x			2
Apricardia pachiniana Sirna	x			3

*=Pachino-Portopalo and Capo Passero undivided

Table of rudists from area 3.4, Tunisia
from: Philip, 1986 (1); Negra & Philip, 1987 (2); Bernet-Rollande & Philip, 1981 (2)

	J. Serraguia	J. El Kebar Unit1	J. El Kebar Units2&3	Ref.
Hippuritids				
Hippuritella [Hippurites] colliciatus (Woodward)		x		2
Pironaea cf.*corrugata* (Woodward)		x		2
Pironaea cf. *timacensis* Milovanović		x		2
Vaccinites braciensis Sladić-Trifunović		x	x	2
Vaccinites ultimus Milovanović			x	2
Hippuritids indet.	x			3
Radiolitids				
Joufia sp.	x	x		2,3
Pseudopolyconites sp.		x	x	2
Rajka spinosa Milovanović			x	2
Others				
Sabinia sp.		x	x	2
Sabinia ranjica tunisiensis Philip	x			1

Table of rudists from areas 3.2, western Italy & 3.5, Algeria and Madagascar.
Hodna, Algeria from Emberger, 1954 (1).Maastrichtian of the Aniene Valley, SW Italy of Parona, 1908. Maastrichtian of Algeria from Kühn, 1932 (or Böhm, 1927?) of Madagascar from Astre, 1931 & Kühn, 1932, cited in Sanchez, 1981 (3)

Hippuritids	
Tetracionites mozambicus Astre	3
Radiolitids	
Radiolitella [Praeradiolites] pulchellus Vidal	1
Radiolites subangeoides Toucas	3
Others	
Sabinia sublacensis Parona	2
Sabinia anienis Parona	2
Sabinia sinuata Parona	2

3.4. Balkan & Eastern Alpine Region

Table of rudists from area 4.1, the Inner Dinarides
from: Fundinia, Montenegro from younger Senonian, Sladić-Trifunović & Pejović, 1977 (1); Fruška Gora from Upper Maastrichtian, Milovanović *et al.*, 1972 (2); Kozluk, Bosnia, Middle or Upper Maastrichtian, Sladić-Trifunović, 1972 (3); Montenegro *B.wiontzeki* from upper Middle Maas., *D. minima* from Upper Maas, *R. maestrichtiana* Middle-Upper Maas, *K. serbica* Maas. undiv.Pejović, 1969 (4); Dragačevo, in blocks from Tertiary Flysch, Sladić-Trifunović, 1967b (5); Montenegro, cit. Pejovic, 1967 (6); Bešpelj, Bosnia, Middle Maastrichtian, Devidé-Nedela & Polšak, 1961 cit. & Polšak, 1965 (7); Inner Dinarides, generalised, Middle Maastrichtian, Milovanović, 1960 (8); Maastrichtian, Pejović, 1969, cit. Sanchez, 1981 (9)

Hippuritids	
Hippuritella cf.*castroi* (Vidal)	7
Hippuritella cornucopiae (Defrance)	3,7
Hippuritella cf.*lapeirousei* Goldfuss	3,7
Hippuritella variabilis Munier-Chalmas	7
Hippurites cf.*acuticostatus* Lupu	3
Hippurites lamarcki Bayle	7
Hippurites [Orbignya] nabresinensis Futterer	3
Pironaea polystyla slavonica (Hilber)	5,7,8
Pironaea fruscagorensis Milovanović *et al.*	2
Radiolitids	
Bournonia wiontzeki Pejović	4
Distefanella minima Pejović	4
Durania canaliculata Pejović	9
Fundinia biscopulata Pejović	1
Joufia reticulata Böhm	3,7
Kuehnia serbica Milovanović	4
Lapeirousia crateriformis (Des Moulins)	8
Lapeirousia crateriformis depressa Milovanović	3
Lapeirousia jouanneti (Des Moulins)	8
Lapeirousia plana Milovanović	3

Lapeirousella cf.*orientalis* Milovanović	3
Laskarevia lamellosa Milovanović	8
Radiolitella maestrichtiana Pejović	4
Sphaerulites solutus Pethö	3
Others	
Sabinia sp.	5
Sabinia anienis Parona	5
Sabinia sublacensis Parona	5

Table of rudists from area 4.2a, Eastern Serbia,
from: Sladić-Trifunović, 1981a (1); 1979 (2); 1977 (3); Milovanović *et al.*, 1972 (4); Milovanović & Sladič, 1957 (5); Pejović, 1967 (6); Milovanović, 1935b (7); Milovanović, 1935a (8)

	U. Camp.	L. Maas.	M. Maas.	U. Maas.	Maas. undiv.	Ref.
Hippuritids						
Hippuritella lapeirousei (Goldfuss)			x			8
Hippuritella variabilis Munier-Chalmas	x					8
Hippuritella [Hippurites] colliciatus (Woodward)	x					8
Pironaea polystyla bacevicensis Milovanović*				x		4
Pironaea branislavi Sladić-Trifunović					x	2
Pironaea polystyla (Pirona)				x		8
Pironaea corrugata (Woodward)	x	x				8
Pironaea corrugata transitoria Milovanović	x					8
Pironaea petkovici Milovanović *et al.*				x		4
Pironaea polystyla milovanovici Kühn*				x		8
Pironaea polystyla slavonica (Hilber)			x			8
Pironaea timacensis Milovanović	x					4
Vaccinites bacevicensis Sladić-Trifunović					x	3
Vaccinites ultimus Milovanović				x		8
Vaccinites loftusi Woodward	x					8
Vaccinites loftusi timacensis Milovanović	x					8
Vaccinites orientalis Milovanović			x			8
Vaccinites styriacus maestrichtiensis Milovanović				x		7
Yvaniella [Yvania] maestrichtiensis Milovanović			x			7
Radiolitids						
Joufia reticulata Böhm			x			8
Lapeirousia crateriformis (Des Moulins)		x				8
Lapeirousia jouanneti (Des Moulins)			x			8
Lapeirousia plana Milovanović			x			7
Neoradiolites serbicus Milovanović				x		8
Praeradiolites aristidis (Munier-Chalmas)		x				8
Praeradiolites boucheroni (Bayle)			x			8
Praeradiolites leymeriei (Bayle)				x		8
Pseudopolyconites bacevicensis Milovanović et Sladić			x			5
Pseudopolyconites balcanicus Milovanović et Sladić			x			5
Pseudopolyconites dechaseuxi Milovanović et Sladić			x			5
Pseudopolyconites giganteus Milovanović et Sladić			x			5
Pseudopolyconites lascarevi Milovanović et Sladić			x			5
Pseudopolyconites manjae Milovanović et Sladić			x			5
Pseudopolyconites mirabilis Milovanović			x			8
Pseudopolyconites orientales Milovanović et Sladić			x			5
Pseudopolyconites ovalis Milovanović				x		8
Pseudopolyconites parvus Milovanović				x		8
Pseudopolyconites serbicus Milovanović				x		8
Pseudopolyconites serbicus triangularis Milovanović				x		8

	U. Camp. L. Maas.	M. Maas.	Maas. undiv. U. Maas.	Ref.
Pseudopolyconites timacensis Milovanović et Sladić		x		5
Radiolites albonensis Toucas	x			8
Radiolites angeoides (de Lapeirouse)	x			8
Radiolites giganteus Milovanović		x		8
Radiolites nouleti timacensis Milovanović	x			8
Radiolites squamosus d'Orbigny	x			8
Radiolites subangeoides Toucas	x	x		8
Branislavia [Sphaerulites] bacevicensis (Milovanović)			x	1,8
Others				
Sabinia rtanjica Pejović		x		6

*known also known as *P. milovanovici*, and*P.bacevicensis*

Table of rudists from area 4.2b, Bulgaria
from Pamouktchiev, 1983 (1); 1979a (2); 1977 (3); 1976 (4); 1975b (5); 1975c (6); 1974 (7); 1969 (8); 1967 (9); 1966 (10); 1965 (11); 1964 (12); 1962 (13); Tzankov, 1965 (14)

	Garlo lower lens	Yarosl. upper lens	Yamb.	other	Ref.
Hippuritids					
Hippuritella [Orbignya] lapeirousei (Goldfuss)	x				12
Hippuritella bulgarica (Toula)		x			3
Hippuritella variabilis Munier-Chalmas		x			13
Hippuritella maestrei Vidal		x			13
Hippuritella maestrei transitoria Pamouktchiev		x			6
Hippuritella heritschi (Kühn)	x	x			2
Hippuritella [Hippurites] colliciatus (Woodward)		x			3
Hippurites nabresinensis Futterer		x			3
Hippurites tzankovi Pamouktchiev				x	4
Pironaea bacevicensis Milovanović	x				2
Pironaea corrugata (Woodward)		x			12
Pironaea milovanovici Kühn	x				2
Pironaea negrichorensis Pamouktchiev		x			5
Pironaea pejovici Pamouktchiev		x			5
Pironaea polystyla garlensis Pamouktchiev	x				11
Pironaea polystyla slavonica Hilber		x			12
Pironaea postdalmatinica Pamouktchiev	x				2
Pironaea praeslavonica Milovanović et al.			x		3
Pironaea praeyaroslavensis Pamouktchiev		x			5
Pironaea signumpraeverta Pamouktchiev	x				2
Pironaea slavonica Hilber			x		3
Pironaea yaroslavensis Pamouktchiev		x			5
Vaccinites archiaci Munier-Chalmas		x			13
Vaccinites atheniensis Ktenas			x		3
Vaccinites [Hippurites] loftusi Woodward		x			13
Vaccinites cf. sulcatus Defrance		x			13
Vaccinites vredenburghi Kühn	x				2
Vaccinites [Hippurites] ultimus Milovanović	x				13
Radiolitids					
Batolites sp.	x				9
Biradiolites acuticostatus d'Orbigny	x				2
Biradiolites aff. heberti Toucas		x			10
Biradiolites aff. mengaudi Ciry	x				10
Biradiolites bulgaricus Pamouktchiev		x			10
Biradiolites bulgaricus giganteus Pamouktchiev		x			10
Biradiolites ingens (Des Moulins)	x				2
Biradiolites postbisulcatus Pamouktchiev		x			10

	Garlo lower lens	Garlo upper lens	Yarosl.	Yamb.	other	Ref.
Biradiolites postunisulcatus Pamouktchiev			x			10
Biradiolites postunisulcatus protentus Pamouktchiev			x			10
Bournonia adriatica Pejović	x					2
Bournonia bulgarica Pamouktchiev	x					2
Bournonia fourtaui Douvillé	x					2
Bournonia garloica Pamouktchiev		x				2
Bournonia putignanensa Campobasso	x					2
Bournonia retrolata (Astre)	x					2
Bournonia wiontzeki Pejovic	x	(x?)				2
Joufia reticulata Böhm	x					12
Lapeirousia crateriformis (Des Moulins)			x			8, 12
Lapeirousia crateriformis depressa Milovanović	x					2
Lapeirousia jouanneti (Des Moulins)	x		x			8, 12
Lapeirousia pervinquierei (Toucas)	x					2
Lapeirousia plana Milovanović			x			8
Neoradiolites serbicus Milovanović		x				2
Praeradiolites cylindraceus (Des Moulins)	x					12
Praeradiolites hoeningshausi (Des Moulins)			x			12
Praeradiolites plicatus desmouliniana (Matheron)			x			12
Praeradiolites sinuatus (D'Orbigny)	x					2
Praeradiolites subcoquandi (Toucas)			x			12
Praeradiolites subtoucasi (Toucas)			x			12
Pseudopolyconites garlensis Pamouktchiev		x				2
Pseudopolyconites timacensis Milovanović et Sladić	x					12
Radiolites angeoides (Lapeirouse)	x					12
Radiolites radiosus D'Orbigny			x			12
Radiolites squamosus D'Orbigny	x					12
Others						
Dessia prima Pamouktchiev		x				1
Mitrocaprina vidali Douvillé	x					7
Mitrocaprina bulgarica Tzankov			x			14
Schiosia bilinguis Böhm	x					7

other= Konska, Isvor nr Yaroslavtzi or Philipovtzi nr Trän

Table of rudists from area 4.3, Romania
from: the southern Apuseni Mnts, Lupu, 1984 (1); Lupu & Lupu, 1981 (2); Lupu, 1977, 1976, 1974 1971, 1970, 1967, Patrulius, 1974 cited for the Maastrichtian of Romania in Sanchez, 1981 (3)

	Borod 2nd Camp.	Borod 3rd U. C-M.	Rosia 3rd Camp.	Remeti C.-M.	Ref.
Hippuritids					
Hippuritella castroi (Vidal)					3
Hippuritella laperousei (Goldfuss)					3
Hippuritella [Hippurites] colliciatus (Woodward)	x				1
Hippurites cornuvaccinum Munier-Chalmas	x				1
Hippurites nabresinensis Futterer	x				1
Vaccinites archiaci Munier-Chalmas			x		2
Vaccinites sulcatus Defrance	x		x		1,2
Vaccinites inaequicostatus Münster	x				1,2
Vaccinites oppeli Douvillé			x		2
Vaccinites vredenburghi Kühn			x		2
Radiolitids					
Bournonia aff. africana Douvillé					2

	Borod 2nd Camp.	Rosia 3rd U.	3rd C-M.	Remeti 3rd Camp.	C.-M.	Ref.
Bournonia bournoni Des Moulins						3
Biradiolites royanus (D'Orbigny)						3
Colveraia secunda Lupu						3
Colveraia sp.		x				1,2
Joufia cappadociensis (Cox)						3
Joufia reticulata Böhm						3
Joufia silvaeregis ?		x				1,2
Joufia						2
Klinghardtites musculosus (Klinghardt)			x			2
Neoradiolites matheroni Toucas	x					1
Orestia oresti Lupu						3*
Praeradiolites aristidis (Munier-Chalmas)						2
Praeradiolites subtoucasi Toucas			x			2
Pseudopolyconites sp.					x	1, 2
Pseudopolyconites hirsutus (Patrulius)						3
Pseudopolyconites milovanovici Lupu						3
Radiolitella pulchellus (Vidal)						3
Radiolites angeoides de Lapeirouse	x		x			1, 2
Radiolites gastaldianus Pirona	x					1
Radiolites squamosus Toucas	x					1
Radiolites subsquamosus Toucas	x		x			1, 2
Others						
Sabinia		x				1

*cited for Upper Senonian

Table of rudists from area 4.4, Hungary, Austria & Czechoslovakia
Hungary, from Czabalay, 1988 (1). Austria, Lupu & Lupu, 1981 (2). Slovakia, Lupu, 1976 (3)

	D	B UC	B LM	S	A	Ref.
Hippuritids						
Hippuritella [Hippurites] colliciatus (Woodward)	x	x				1
Hippuritella [Hippurites] lapeirousei (Goldfuss)			x			1
Hippurites heritschi Kühn	x					1
Vaccinites oppeli (Douvillé)	x					1
Vaccinites braciensis Sladić		x				1
Radiolitids						
Bystrickya andrusovi Lupu				x		3
Joufia reticulata Böhm					x	2
Pseudopolyconites sp.				x		3

1, D= Dédestapolcsány in the Campanian; B= Balkony Mt., UC Upper Campanian, LM, Lower Maastrichtian
2. Upper Hron Valley, Slovakia, Czechoslovakia
3. Wittersdorf, Carinthia

3.5 Middle Eastern Region

Table of rudists from area 5.1 Turkey
from: south-eastern Turkey, Karacabey-Öztemür, 1981b (1). Central southern Turkey, 1981a (2); 1980 (3); 1976 (4); 1974 (5); Karacabey, 1970 (6); 1969 (7); 1968 (8). Northwest Turkey, Böhm, 1927 cit. Kühn 1933 (9). Central Turkey,Woodward, 1855 cit. Cox, 1960 (10); northern Turkey, Stchepinsky, 1941, 1942 cit. Cox, 1960 (11); southern Turkey, Stchepinsky 1944 cit. Cox, 1960 (12).

Hippuritids	
Hippuritella [Hippurites] colliciatus (Woodward)	10,12
Hippurites blanckenhorni Böhm	9
Hippurites corunvaccinum Bronn	9, 11
Hippurites gosaviensis Douvillé	9
Hippurites tenuicostata Böhm	9
Hippurites bithynicus Kühn	9
Pironaea [Hippurites corrugatus] corrugata (Woodward)	6,10,12
Pironaea corrugata timacensis Milovanović	4
Pironaea polystyla anatolica Karacabey	6
Pironaea polystyla slavonica (Hilber)	7
Pironaea praeslavonica Milovanović *et al.*	1,2
Vaccinites braciensis Sladić-Trifunović	4
Vaccinites giordani Pirona	6
Vaccinites [Hippurites] loftusi (Woodward)	1,10,11,12
Vaccinites [Hippurites] vesiculosus (Woodward)	10,12
Yvaniella alpani Karacabey	8*
Yvaniella maestrichtiensis Milovanović	8*
Radiolitids	
Balabania	3
Biradiolites scyphus Böhm	9
Colveraia darendeensis Karacabey-Öztemür	5
Colveraia variabilis Klinghardt	5
Darendeella anatolica Karacabey-Öztemür	4
Durania cf.*spadai* Parona	9
Joufia cappadociensis (Cox)	4,7
Joufia cappadociensis melitenensis Karacabey-Öztemür	5
Joufia reticulata Böhm	4
Lapeirousia jouanneti (Des Moulins)	11, 12
Kurtinia hemisphaerica Karacabey-Öztemür	3
Miseia hekimhanensis Karacabey-Öztemür	1
Miseia osculata Karacabey-Öztemür	1
Miseia regularis Karacabey-Öztemür	1
Praeradiolites sinuatus (D'Orbigny)	9
Radiolites angeoides (de Lapeirouse)	9
Radiolites endrissi Böhm	9
Radiolites cf. *subangeoides* Toucas	9
Vautrinia syriaca (Vautrin)	2, 12
Others	
Dictoptychus euphratica Karacabey-Öztemür	2
Dictoptychus orontica Karacabey-Öztemür	2
Sabinia klinghardti Böhm	9

*given the co-occuring *Vaccinites* species there is no reason to suppose that these forms are not Lower Senonian
rudists from reference 9 are all thought to be of the same age range U. Sant.-L. Camp. by Böhm or U. Camp-Maas. by Kühn

Table of rudists from areas 5.2 & 5.3, Iran, Afghanistan, southern USSR & Syria

Iran from Kühn, 1932 in Vogel, 1970 (1) Iran, Douvillé, 1904 (2). Southern USSR, Yanin, 1988 (3); Iran, Syria & Afghanistan, Vogel, 1970, 1971; Grubić, 1963, 1962; Nazemi & Grubić, 1959 (Afghanistan), Bobkova, 1960; Vautrin, 1933; Kühn, 1932; (Afghanistan) Douvillé, 1910; from the Maastrichtian cited in Sanchez, 1981 (4); Douvillé, 1913, cit. Chubb, 1956 (5).

	S. Iran*1			E. Iran	I*2	A	S	R	Ref.
	1	2							
		E	C						
Hippuritids									
Hippuritella colliciatus (Woodward)					x				4
Hippuritella lapeirousei (Goldfuss)									4
Hippuritella morgani (Douvillé)					x				4
Hippurites cornucopiae Defrance			x		x				2,4
Hippurites vlasovi Bobkova						x			4
Hippurites								x	3
Pironaea persica Vredenburg					x	x			4*3
Vaccinites vredenburghi (Kühn)					x	x			4*3
Vaccinites								x	3
Radiolitids									
Biradiolites siracensis Toucas									4*3
Biradiolites								x	3
Bournonia								x	3
Durania [Biradiolites] austinensis Römer		x			x				2
Lapeirousia darwaseana Bobkova					x	x			4
Lapeirousia jouanneti (Des Moulins)					x				4
Lapeirousia								x	3
Osculigera cleggi Kühn				x		x			1
Osculigera hippuritiformis Kühn				x					1
Osculigera magna Kühn				x					1
Osculigera vautrinioides Vogel									4
Radiolites endrissi Böhm							x		4*
Radiolites subangeoides Toucas							x		4
Radiolites								x	3
Vautrinia syriaca (Vautrin)				x			x	x	3,4
Thyrastylon persicus Douvillé					x				5
Others									
Artigesia								x	3
Dictyoptychus [Polyptychus] morgani Douvillé		x							2

*1 Douvillés's 1st and 2nd localities as used in text.
E= "Couches à Échinides", C= "Couches à Cérites"
*2 I= Iran general, A= Afghanistan S= Syria Iq= Iraq R=Southern USSR
*3 Upper Senonian

6. Arabian Region

Table of rudists from area 6.1, the Oman Mountains in U.A.E
from Skelton *et al.*, 1990 (1) Chubb, 1956, cit. Skelton & Wright, 1987 (2)

	Q.M. M1	J. F. M2	J. H. L. Q	U. Q	L.S.Ref.	
Hippuritids						
Hippurites cornucopiae Defrance		x				1
Hippurites cf. *nabresinensis* Futterer		x				1
Vaccinites braciensis Sladić-Trifunović	x					1
Vaccinites loftusi (Woodward)				x		1
Vaccinites cf.*oppeli* Douvillé					x	1
Vaccinites vesiculosus (Woodward)				x		1
Pironaea ?corrugata (Woodward)	x					1
Pironaea ?praeslavonica Milovanović *et al.*	x					1
Torreites sanchezi milovanovici Grubić	x		x			1
Vautrinia sp. cf. *Osculigera vautrinioides* Vogel	x					1
Radiolitids						
Bournonia excavata (d'Orbigny)	x					1
Bournonia sp.		x		x		1
Biradiolites aquitanicus Toucas		x			?x	1
Biradiolites sp.	x			x		1
Durania cf.*austinensis* (Roemer)		x				1
Durania sp.					x	1
Pseudopolyconites sp.	x					1
Praeradiolites cf. *aristidis* (Munier-Chalmas)		x				1
Colveraia sp.	x	x				1
Others						
Sabinia sp.	x		x			1
Dictyoptychus morgani (Douvillé)		x		x	x	1
Plagioptychus sp.		x				1
Thyrastylon						2

Localities are Qarn Murrah (QM), Jebel Faiyah (JF), Jebel Huwayyah (JH)
Formations are Qahlah Fm (Q), Simsima Fm (S)

Table of rudists from area 6.2a, Southern Oman
from Philip & Platel, 1987

	Sanham Fm Lower	Sharwayn Fm Upper
Vaccinites vesiculosus (Woodward)		x
Torreites milovanovici Grubič	x	
Durania	x	
Praeradiolites	x	
Bournonia	x	
Biradiolites	x	

Table of rudists from area 6.2b Central Saudi Arabia
from Skelton & El Asa'ad (unpubl.)

	Aruma Fm top Kh.	L.Haj. 1	L.Haj. 2	U.Haj.
Radiolitids				
Durania cf. *cornupastoris* (Des Moulins)	x			
Durania gaensis (Dacque)	x			
Biradiolites lombricalis ?		x		
Biradiolites sp.	x			
Bournonia excavata d'Orbigny		x		
Bournonia ?bournoni (Des Moulins)		x		
Others				
Dictyoptychus morgani (Douvillé)			x	
nov. gen. nov. sp.	x			
Apricardia pachiniana Sirna		x		
?Bayleia sp.				x

1=top of the cyclolitid marls
2=lower part of calcareous portion

7. Northern European Region

Table of rudists from area 7, northern Europe
the Maastrichtian of Holland: cited in Philip & Bilotte, 1985 (1); Kühn, 1932, cited in Sanchez, 1981 (2)

Hippuritids	
Hippuritella lapeirousei (Goldfuss)	1
Vaccinites sulcatus maestrichtiensis (Kühn)	2
Radiolitids	
Biradiolites royanus (D'Orbigny)	1
Lapeirousia trigeri (Bayle)	2
Praeradiolites cremersi ?	1
Praeradiolites faujasi (Bayle)	1,2
Praeradiolites hoeningshausi (Des Moulins)	1

8. Caribbean Region

Table of rudists from area 8, the Caribbean, Maastrichtian of Jamaica & Cuba, from Chubb, 1956

	Jamaica		Cuba	
	B. beds*	T. beds*	B. Beds	t. beds
Hippuritids				
Barrettia gigas Chubb	x			
Barrettia monilifera Woodward			x	
Barrettia multilirata Whitfield	x		x	
Hippurites ceibarum (Chubb)		x		
Hippurites mullerriedi (Vermunt)		x		x
Parastroma maldonensis Chubb		x		
Parastroma sanchezi Douvillé			x	
Parastroma guitarti (Palmer)				x
Praebarrettia porosa Palmer				x
Praebarrettia sparcilirata Whitfield		x		x
Torreites sanchezi (Douvillé)			x	
Torreites tschoppi Macgillavry			x	
Vaccinites macgillavryi Palmer			x	
Radiolitids				
Agriopleura falconi Chubb		x		
Biradiolites cf. *acuticostaus* d'Orbigny			x	
Biradiolites cf. *aquitanicus* Toucas			x	x
Biradiolites cubensis Douvillé			x	
Biradiolites forbesi Chubb		x		
Biradiolites jamaicensis Trechmann		x		
Biradiolites cf. *lameracensis* Toucas			x	
Biradiolites lumbricoides Douvillé				x
Biradiolites macgillavryi Vermunt			x	
Biradiolites minhoensis Trechmann		x		
Biradiolites rudis (Whitfield)		x		
Biradiolites rudissimus Trechmann		x		
Biradiolites tschoppi Vermunt			x	
Bournonia barretti Trechmann		x		
Bournonial cf. *bournoni* Des Moulins				x
Bournonia cancellata (Whitfield)		x		x
Bournonia planasi Thiadens				x
Bournonia thiadensi Vermunt				x
Bournonia n. sp. Chubb	x			
Chiapasella bermudesi Palmer				x
Chiapasella cubensis Rutten			x	
Chiapasella pauciplicata Mullerried				x
Chiapasella radiolitiformis (Trechmann)		x		
Durania cf. *aguilae* Adkins	x			
Durania curasavica (Martin)			x	
Durania lopeztrigoi (Palmer)			x	
Durania nicholasi (Whitfield)	x	x		
Radiolites annulosus Whitfield		x		
Radiolites galofrei (Palmer)				x
"Radiolites macroplicatus" Thiadens			x	
Sauvagesia annulosa (Whitfield)				
Sauvagesia fluminisagni Chubb		x		
Sauvagesia macroplicata (Whitfield)		x		
Sauvagesia mcgrathi Chubb		x		
Parabournonia hispida Douvillé			x	
Praeradiolites verseyi Chubb	x			

Tampsia rutteni Vermunt		x	
Thyrastylon adhaerens (Whitfield)		x	
Thyrastylon coryi (Trechmann)		x	
Thyrasylon semiannulosus (Trechmann)		x	
Others			
Gyropleura shaviensis Chubb		x	
Monopleura jamaicensis Chubb		x	
Antillocaprina annulata (Palmer)			x
Antillocaprina crassitela MacGillavry		x	
Antillocaprina occidentalis (Whitfield)		x	
Antillocaprina quadrangularis (Whitfield)		x	
Antillocaprina pugniformis (Palmer)			x
Mitrocaprina multicanaliculata Chubb		x	
Mitrocaprina tschoppi (Palmer)			x
Plagioptychus antillarum (Douvillé)		x	
Plagioptychus jamaicensis (Whitfield)		x	
Plagioptychus minor Chubb		x	
Plagioptychus toucasi Matheron	x		
Plagioptychus trechmanni Chubb		x	
Plagioptychus zansi Chubb		x	
Titanosarcolites giganteus (Whitfield)		x	x

Barrettia beds, *Titanosarcolites* beds

Suggested taxonomic revisions

The rudist names listed in these tables should be taxonomically correct according to the present state of the art. However, with such a widespread distribution, large number of specimens and a century and a half of literature, there is unsurprisingly a great need for taxonomic revision - a task well beyond the scope of this work. Yet some attempt must be made to assess the validity of the different species and genera in order to consider the relative diversity of forms, through time and between different palaeobiogeographic areas.

The disarray in classification results partly from different interpretions of what constitutes a fossil species. In one school of thought, the species is exemplifed by the specimen originally chosen as the holotype. A later specimen which resembles the holotype in most ways, but which in one or more is different, by definition is not the same; it may be regarded as a new subspecies, species, or even genus dependent upon the amount of difference between it and the holotype specimen (always a highly subjective decision). This approach has lead to "splitting" ie. the establishment of a large number of names to encompass the variety of forms.

According to the other school of thought, which I follow, a fossil species is viewed in the same way as a living one. The species comprises several populations, each population numerous individuals, and each individual is slightly different from the other. Considering all the characteristics, there is a range of continuous variation between those individuals. However, they may be characterised by an "average", or "typical" form - though that may be different between different populations. This perspective has lead to "lumping" of slightly different forms under the same species name. For this school the holotype, which happened to be the first, or one of the first, examples to be described of that species is not necessarily the most representative, a difficultly partly relieved by the description of paratypes to demonstrate the range of variability encompassed by the species. Unsurprisingly there is an unwillingness to establish a new species from only one example unless it is unquestionably distinct.

The consequence of this difference in definition of a species - between the school of typological methodology and those who follow a biological species concept - is that the former perceive greater diversity than the latter. So merely by merely looking at these lists of species, without considering how they have been named, the reader gets the mistaken impression that some areas are firstly far more diverse than others and secondly have a almost totally endemic fauna - when in fact the fauna is little different from that of adjacent regions.

The natural variability present between different individuals of, what I consider to be, the same rudist species encompasses ecophenotypic, ontogenetic and preservational variation. To my mind the external morphology of rudists is highly dependent on habitat, which can be seen when a species is founded on a population, as there is often quite a variety of forms with a spectrum of continuous variation between them. Strictly speaking, only the extent of ecophenotypic variation should be a point of contention between the different schools of thought and ontogenetic and preservational variation should have been taken into account by all workers.

Ontogenetic variation may be quite significant in some genera, particularly hippuritids. As a rudist shell enlarges it may change the relative position or shape of its internal or external features, such as size and shape of the ligamentary crest, pillars/radial bands, all of which are species-diagnostic characteristics. When only one section (and worse still, one oblique section) is taken of each shell, and there is such ontogenetic variation, forms may be considered different species when in fact they are the same.

Different modes of preservation have frequently led to the creation of additional, superfluous species names. The problem is particularly acute for those rudists defined on the shape of canals in inner shell layers, such as *Colveraia*. Rudists have two main layers of calcium carbonate in their shells, an inner layer which was originally made of aragonite and an outer of calcite. During diagenesis the aragonite recrystallises to calcite which, if it had proceeded by a simple one-stage process of gradual replacement would not have significantly altered the internal characteristics. However if the diagenesis has been complicated, involving such

processes as, for example micrite coatings, aragonite dissolution and then the start of cavity infilling, then the original pattern of holes (as seen in section) will have been altered. There are also several examples in the literature where incomplete or eroded specimens have been unknowingly described. A frequent mistake is the description of specimens - particularly radiolitids - which are no more than the recrystallised inner layer attached to the sediment infill (known as a *birostra*, or *birostre*) and lacking the all-important outer calcitic layer .

There have been further problems in the establishment of a consistent taxonomy for European rudists due to the political situation in Europe over the last century. With the proliferation of the literature, but the difficulty of access to post-war sources between eastern and western Europe authors have not neccessarily checked all records of known species before creating new ones. Additionally many illustrations have been of too poor quality and descriptions not in common languages for them to be understood. Fortunately most authors have had access to the works of Douvillé (cited in Toucas) and Toucas (1903, 1907-10). The species described, or redescribed in these have in general stood the test of time and are a basis for much subsequent work. Indeed most authors prefer to use these works than the section in the treatise (Dechaseux *et al.*, 1969) which contains many errors and, in my opinion, is too uncritical in the adoptions of certain records.

However there are other problems associated with using these older French works as the reference works. Most of the Pyrenean faunas come from marly limestones where the rudists weather out of the sediment and descriptions tend to concentrate upon the external morphology, such as the radial bands in right valve of radiolitids or the pores on the left valve of hippuritids. In the purer limestones of central Tethys it may be impossible to extract whole specimens and more reliance is place on internal morphology as seen in sections of the rock and fossil. Moreover in the more calcareous sediments longer, pipe-like forms are quite common and they are not present in the youngest rudist strata of the Pyrenees. Many of these have been described as new genera when they may be merely different growth forms of existing genera.

For the reasons outlined above I would like to suggest several informal changes to the rudist lists. Several genera created by workers of the typological school I will reduce to the rank of

species, some species are reduced to subspecies and varieties are dispensed with. Species defined on and still restricted to one specimen I will reject - unless they are clearly different from all other species of that genus. In addition there are several other genera of dubious repute which I will discuss separately. It is regrettably too large a task to comment on all possible synonomies of species. I should like again to stress that the foregoing remarks are not based upon a rigorous study of all the holotypes, paratypes and regional examples of the genera under discussion. Instead they are merely suggestions for a reclassification which would create a clearer picture of the affinities of faunas between the different regions and their relative diversities.

Hippuritidae

The main genera *Vaccinites, Hippurites* and *Hippuritella* are fairly well defined in terms of genera and species (but see introduction). However there is very little difference in the two small and plainest forms *Hippurites nabresinensis* and *Hippuritella lapeirousei* which both have small, widely spaced, weakly bulging pillars and a slight inwards bulge at the site of the ligament. *Hippurites nabresinensis* is usually the name given to the Lower Senonian forms and *Hippuritella lapeirousei* to the Upper in which case the senior form *Hippuritella lapeirousei* should have priority. *Pironaea* , a long standing genus is a taxonomic headache at the species level. A vast number of new species have been created by Milovanović and by subsequent workers from the same school, Sladić-Trifunović and Pamouktchiev which other workers suspect may be mostly ontogenetic (see eastern Serbian section of chapter 5 for more details). I have therefore reduced the diversity of species by half in the Internal Dinarides and eastern Serbia in calculating the diversity in the conclusions.

The enigmatic *Yvaniella* was defined by Milovanović on the basis of one, much illustrated specimen from eastern Serbia and this remains the only example apart from a report by Karacabey-Öztemür, 1968 of a new species of this genus. In all features Milovanović's *Yvaniella* is a *Hippuritella* (perhaps *Hlla* cf.*bulgarica*) except that it has a short turret with two holes on the top on the left valve (rather like a pig's snout). It looks like a slightly mutant *Hippurites* pustule on top which has been eroded away displaying some of the radial canals. Either way, there is, to my mind, insufficient evidence for a new genus. The

specimen of *Yvaniella* f. *maestrichtiensis* reported by Karacabey, 1968 from Turkey did not have a left valve and the diagnosis was made solely on similarities of the right valves. Karacabey also created a new species *Yvaniella alpani* which is a normal, but slightly slightly crushed *Hippurites/Hippuritella* eroded across the top.

The three mainly American hippuritids, *Torreites* and *Barrettia* and *Praebarrettia* have other systems of infolding and modification to the outer shell wall, derived at independently to *Pironaea* . *Parastroma* is another American hippuritid fairly well accepted in the literature.

Radiolitidae

The following genera seem fairly well defined since Douvillé's work: *Radiolites, Praeradiolites, Lapeirousia, Sauvagesia, Durania, Biradiolites* and *Bournonia.* They fall fairly conveniently into four subfamilies created by Douvillé partly on the basis of the characteristics of the radial bands. The subfamilies were adopted in the treatise (Dechaseux *et al.* 1969) but stressing the shape of the cells in the outer layer of the right valve, which Douvillé had resisted as he saw further complications. However, the use of Douvillé's subfamilies still remains a useful practical way of describing the variety of forms. The forms *Radiolitella, Pseudopolyconites* with canals and spines in the outer shell layer also fit into this grouping. However, those, probably related, forms with canals in the inner shell layer should be placed in a separate group.

Radiolitinae

The Radiolitinae are exemplified by *Radiolites* and *Praeradiolites.* They have ligaments, radial bands which are smooth and not involving deflection of the growth lines (as seen on the outside of the shell) and it is also true that they mostly have quadrangular cells.

According to Pons (pers. comm., 1987), *Sphaerulites* is just an outsize *Radiolites* (or *Praeradiolites*) with recurved laminae towards the outside, a feature of predominant lateral rather than vertical growth. These lists only include one *Sphaerulites* as the rest of the "Maastrichtian" species have been placed in other genera - many in the similarly shaped *Lapeirousia* and others in *Radiolites* . In fact, the specimen of *Sphaerulites solutus* figured by Sladić-Trifunović looks externally extremely similar to some of the *Biradiolites* from

Bulgaria. I know nothing of its internal characteristics (if indeed, it was sectioned). Milovanovic, 1960 also thought that it was not a *Sphaerulites* .

Apulites is known from very few records of two species. It is a long form with slight longitudinal ribs, quadrangular cells and no ligament. It could just as easily be a cylindrical *Bournonia* .

Gorjanovicia is again an elongate, cylindrical radiolitinid with regular ribbing, lamellar shell structure and a small triangular ligament. It differ from *Radiolites* in the lamellar shell structure, and from *Bournonia* in the small ligament . However *Gorjanovicia* is generally regarded as Lower Senonian and the only report of it in the Upper Campanian - Maastrichtian is from the Pučišća Fm of Brač island in beds of which I revise the age to Lower Campanian.

Lascarevia, mentioned in name by Milovanović, 1960 was finally described by Milovanovic, 1984 so that it is not *nominum nudum* (as it was correctly so in the treatise of 1969). It is known from a fragment of one specimen which seems to be a large radiolitid with particular undulations on the growth surfaces. In these it might be *Praeradiolites* but it is insufficiently known for a new genus (or species).

Pons' *Rossellia xavieri* from Spain he now regards as another species of *Praeradiolites* (pers. comm., 1987). The "one-banded monster" from Spain is something of an enigma. It is known from numerous specimens and seems rather like a particularly rough *Praeradiolites* or *Radiolites* with recurved growth laminae towards the edge, a ligament and polygonal cells (not common in these genera). However, the salient feature of one very prominent radial band is quite different from anything known previously and ranks at least as a new subgenus.

The Slovakian *Bystrickya* named by Lupu is probably a *Praeradiolites*. *Kurtinia* was named by Lupu and the one species *K. hemisphaerica* has also been reported by Borgomano & Philip, 1987 from S. Italy. I have no details of these

Eoradiolites is a non-descript, primitive radiolitid with two wings but without radial bands. It is quite well known from the middle Cretaceous Albian-Coniacian in various different areas of Tethys but there is also a claim by Camoin *et al.*, 1983 to have found it in Sicily in Maastrichtian strata.

Radiolitella is a fairly well established genus and is a *Radiolites* but with some larger polygonal "cells" in the inner part of the outer shell layer which are in fact longitudinal canals.

Kuehnia is known from one species, *K. serbica* of Milovanović, 1956. It has a well-developed ligamentary crest which bifurcates at the end and some larger cavities on the inside of a cellular layer with rectangular cells. It seems similar to but not identical to *Radiolitella* and I will treat it at the rank of subgenus. *Pseudokuehnia* of Sliškovič, 1971 is also known from one species *P. milovanovici* and Sladic-Trifunovic & Campobasso claim to have found several specimens in Salento though these are unfigured.

Pseudopolyconites is a *Praeradiolites* where the pattern of ridges, which are so common on the inside of the growth surface of the outer shell layer, has been modified to spines. It is the only spinose genus and relatively easily identifiable when sectioned. The Romanian *Duranddelgaia* invented by Patrulius has since been renamed as *Pseudopolyconites* as has Klinghardt's *Radiolites pasani* from M. Jouf (Sladić-Trifunović, 1987). A large number of new species of *Pseudopolyconites* have been created for the beds in eastern Serbia (Milovanović & Sladić, 1957; Sladić-Trifunović, 1983 and there are also several species names given in this paper which were never described so are *nomina nuda*). They are certainly not all the same, but the differences between them are often very slight and in comparison with other radiolitids I think that the diversity of *Pseudopolyconites* species has been overestimated.

Biradiolitinae

The Biradiolitinae are forms without ligaments and with smooth radial bands and a deflection of the growth lines in the interband. They also mostly have quadrangular, or amoeboid cells (Amico, 1978) cells or sometimes a compact structure.*Biradiolites* and *Bournonia* are

acceptable to me as different genera although they seem to represent distinct end points of a wide range of variability. In general *Biradiolites* refers to forms with steep growth lines and sharp zig-zag folds and ribs, whilst *Bournonia* is smooth but often with two prominent folds or wings. At the species level *Bournonia* and *Biradiolites* are problematic. A large number of small *Bournonia* species have been recorded in the muddy deposits of the inner platform, such as the Vreme beds at Dolenja Vas and their probably equivalent, the Brač Fm on Brač Island. With one, often poorly preserved section of each shell, when not even the growth lines can be seen clearly, it is impossible to assess the extent of ontogenetic variation and to be certain of the clear identity of new species. It is possible that these accounts overestimate the diversity of these forms. Additionally many small specimens are assigned to what is, in my opinion, the wrong genus from the two genera,*Bournonia* and *Biradiolites*. For example I found this situation in Bulgaria where I distrust all the diagnoses of small *Bournonia* specimens - most are to my mind *Biradiolites*. Moreover *Biradiolites ingens* from Bulgaria I would describe as *Bournonia* sp.

The spanish uppermost Cretaceous forms of *Agriopleura* are to my mind more cylindrical versions of *Bournonia* (as suggested by Masse & Philip, 1974). Certainly *Agriopleura garumnica* and probably *A. moroi* has the requisite quadrangular cells in the outer part of the outer layer but the inner part is compact. The same is true in certain *Bournonia* species such as *B. excavata* .

The easily recognisable form *Rajka, R. spinosa* , is no more than a highly crenulate *Biradiolites* such as the already defined *B. orbignyi* Toucas (Pons, pers. comm., 1987). The genus created by Karacabey-Ötzemür from Turkey, *Darandeella anatolica* is another large crenulate *Biradiolites* such as *B. lameracensis* Toucas.

There are several pipe-like radiolitids from Yugoslavia which I consider to be further representatives of the genera *Biradiolites* and *Bournonia*. For instance *Milovanovicia*, originally named from several Turonian species by Polšak (1967) is another winged *Biradiolites* or *Bournonia*, but particularly elongate, with no ligament or pseudopillars and sometimes lacking cells (which is not uncommon in pipe-like forms which have concentrated

on rapid upward rather than sideways growth). *Petkovicia* is similar but with pseudopillars and with fine cells.

Radiolites pseudomonopleura named by Klinghardt from M. Jouf, northern Italy is an internal mould of *Bournonia.*

Batolites is described from "Maastrichtian" strata of Bulgaria (Pamouktchiev, 1967) and in the Lower Senonian [Coniacian-Santonian?] of France and the Eastern Alps (Dechaseux *et al,* 1969). I am uncertain of the diagnosis of the Bulgarian specimen which is described from one section of a right valve. It could be another small ribbed hippuritid or and could be a radiolitid with extreme pseudopillars and no visible cells.

Distefanella is a winged *Bournonia/Biradiolites* first recorded by Parona (Parona, 1901, cit. Sanchez, 1981). Of the several known species most are either Turonian, or at any rate Lower Senonian.[Coniacian-Lower Campanian] Pejovic, 1969 mentions a new species of this genus *D. minima* from Montenegro named from one, probably oblique section of a poorly preserved specimen. For me this record represents insufficient information to warrant its inclusion.

Fundinia is another winged form, but with canals. It is known from one species, from Brač Island and Fundinia in Montenegro (Sladić-Trifunović & Pejović, 1977). It has two wings, one larger than the other and a few particularly large canals, round in section in an otherwise cellular layer. It is sufficiently distinctive to be called a new genus.

Katzeria is a plain, small form, mostly likely to be a radiolitid, though of no obvious group, with slight pseudopillars and no obvious ligament. It also has no cells (probably a derived feature) but a strange stripy appearance, probably a slight diagenetic modification of a finely ribbed growth surface (as in hippuritids). It is quite distinctive and deserves to stand.

Sauvagesiinae

The Sauvagesiinae, as exemplified by *Sauvagesia*, have a small ligamentary crest without obvious termination and fine ribbing on the radial bands whilst the ribbing on the rest of the shell is much coarser. Cells tend to be polygonal. The other main genus of this group,

Durania is similar but lacks the ligamentary crest. There are also some other generic names included in this group. For example *Medeella* (Parona, 1924, cit. Sanchez, 1981), which is characterised by an appearance like a pile of stacked cones due to regular variations in the diameter of new growth laminae. It seems very similar to *Sauvagesia* as both have small ligaments and polygonal cells. The ornamentation on the radial bands is different, but given the fact that *Medeella* is an elongate and *Sauvagesia* more a squat form the amount of difference is really at the subgenus, rather than the genus level (as it is in the Treatise). *Fossulites* is also treated as a subspecies of *Medeella* in the Treatise. The only "Maastrichtian" example of this genus is from the "Maastrichtian" rudist limestone at Dolenja Vas, S. Slovenia, though this example strongly resembles *Sauvagesia*. Patrulius, 1974 from Romania introduced the name *Miseia* for a rudist of probably Lower Senonian age. This is in all features *Sauvagesia* and the canals reported from the left valve seen to be little more than external ribs. Karacabey-Öztemür has reported three new species of *Miseia* which are, to my mind, undoubtedly *Sauvagesia*.

Lapeirousiinae

Several genera share the peculiar structure of the radial band which defines the flower-shaped *Lapeirousia*. This feature is essentially a depression in the growth surface which is deflected inwards as a so-called pseudopillar into the body chamber. On the outside the laminae are split and then have re-fused into a seam. The top of the pseudopillars of the RV are covered only by a very thin shell layer in the left valve which is easily eroded away, so creating the appearance of two kidney-shaped eyes or oscules. *Lapeirousella*, created by Milovanović, 1938 as a subgenus is recorded from Sicily and the Inner Dinarides. It is in all significant features a *Lapeirousia*, but with less well developed pseudopillars and I would view it as another species of *Lapeirousia*.

The eastern Tethyan form *Osculigera* (Kühn, 1932, see Vogel, 1971) is also very similar to *Lapeirousia* but distinguished by a peculiar structure of beaded rays and due to slight inflections of the growth laminae along the centre of folds on the commissure. *Vautrinia* (Milovanović, 1938) is so similar to *Osculigera*, that it should be renamed.

Radiolitids with canals in the aragonitic layer

The genus *Joufia* , described by Böhm (1898) from M. Jouf, N. Italy is highly distinctive with the canals in the outer shell layer of the left valve (LV). Klinghardt, 1921 who added to that description also noted the large myophores with a tooth-like structure. In section therefore the myophore, which is an inner part of the inner, aragonitic shell may show prismatic, or elliptical cavities. In one specimen which I found on M. Jouf these cavities appear to extend through the adjacent portion of the inner shell layer and seem to have been formed by the bridging of an accessory cavity between the outer shell layer and the myophore, with a series of partitions, the partitions being in line with the solid teeth of the myophore. In some specimens I have seen, as well as one figured by Klinghardt these even seem to extend right round to the ventral part.

In *Colveraia* which is also described from M. Jouf by Klinghardt, it is the cavities in the inner shell layer rather than the myophore which are developed to the greater extent. In Klinghardt's figured examples the shell was diagenetically altered and the cavities instead of being clearly oval seemed blurred and wispy (a feature known from other altered inner shell layers with canals such as *Sabinia*, see Philip & Platel, 1987). However, in *Colveraia* there are no *Joufia* -like canals in the calcitic layer of the LV which instead is of compact, acellular calcite and extends right over the outer cellular layer of the RV. The right valve (RV) of *Joufia* and *Colveraia* are indistinguishable. Klinghardt also recorded a new species of *Radiolites, R. musculosus* from M. Jouf. This is a from a cross-section of a well-preserved *Colveraia* showing good oval cavities. Sladić-Trifunović later called this form a new genus *Klinghardtites musculosus* . Sladić-Trifunović's *Branislavia* does not warrant separation from *Colveraia* at the generic level if at all (given the variable nature of *Colveraia variabilis*).

Karacabey has renamed the *Parasauvagesia cappadociensis* of Cox as a new species of *Joufia*. This differs from *J. reticulata* in having only one row rather than several of canals in the outer layer of the left valve, a difference which seems valid. Karacabey-Öztemür later figured more specimens of this under the name *Joufia cappadociensis melitenensis* which is essentially the same. Karacabey-Öztemür's *Colveraia darendeensis* differs negligibly from *C. variabilis* . The same author (Karacabey-Öztemür, 1980) also named two genera, *Balabania* and *Kurtinia*, which seem to be intermediates between *Colveraia* and *Joufia*.

Lupu has named some other species of *Colveraia* and *Joufia* but I am uncertain on what grounds.

Neoradiolites as the "Maastrichtian" *N. serbicus* of Milovanovic is recorded by two examples, one from eastern Serbia (Milovanović, 1937) and the other in Bulgaria (Pamouktchiev, 1979a). The Serbian example is described as having a conical LV, slightly curved with a fairly prominent ligamentary crest and a thick layer of prismatic cells. The other valve is curved, and canaliculate with fine canals on the outside giving a stripy external appearance (where a very thin outer shell layer must have eroded away). Milovanovic recognised the resemblance to *Sabinia klinghardti* Böhm but dismissed it saying that the distribution of external characters was quite different. However, they seem remarkably similar to me to those in the British Museum from north-western Turkey (which include the holotype). The Bulgarian example is in my opinion another "*Sabinia*," but not *S. klinghardti*. Both valves have canals which appear as striations on the surface when the very thin 1-2mm calcitic layer has eroded away. The specimen is unlikely to be a birostra of a specimen which once had a thicker calcitic layer because the thin shell is encrusted by bryozoans. Most interestingly the calcite on the RV may have the remains of small infilled cells. I have no information about the *Neoradiolites matheroni* from Romania but I suspect that it is also a "*Sabinia*."

Others: Caprinidae, Caprotinidae, Plagioptychidae, Antillocaprinidae, Monopleuridae and Requieniidae

Representatives of the primitive, uncoiled rudists, the Requieniidae are apparantly restricted to *Apricardia* and *Bayleia* in the Maastrichtian but the species need revision. Primitive *Monopleura* -like forms such as *Gyropleura* have not evolved far from their uncoiled ancestors and look very similar. In fact Pleničar's records of "*Gyropleura* " as the thin-walled form which shows some coiling are probably what other authors consider *Apricardia*. The monopleurid which is recorded from the Lower Eocene of the USSR (see Dechaseux *et al*, 1969), *Paramonopleura* is thought to be *Gyropleura*. There is also *Artigesia* from Aquitaine and the USSR. The strange Danian *Chypiella* (Heinberg, 1979, cit. Kauffman &

Johnson, 1990) which is only slighly inequivalved is closest to a Requieniid, or even to a non-rudist megalodontid bivalve.

There are various canaliculate forms which in the treatise are placed in the Caprinidae. Those canaliculate forms reported in this work include *Mitrocaprina* with canals in the right valve, and the Spanish *Rousselia* , with canals in the left valve. *Dictyoptychus* is well known from eastern Tethys and there is also the new genus, similar to *Dictoptychus* shortly to be described from Saudi Arabia. There is also *Plagioptychus* which has a widespread distribution all over European-African-Asian and Caribbean Tethys. *Coralliochama* is a Caribbean genus. All of these would be placed by Skelton in the Plagioptychidae (see Skelton, 1978).

Sabinia, is a taxonomic problem as at least one species, *"S". klinghardti* should be in the Radiolitidae. It is also possible that many examples identified as *S. anienis* , such as those in Murges, southern Italy, are in fact *S. klinghardti* (P.W. Skelton, pers. comm.) because they have a thick celluar layer in the RV rather than a very thin, compact layer. The three species named originally by Parona, *S. anienis, sinuata* and *sublacensis* may all be the same. The Bulgarian record of the genus *Schiosia* is incorrect because that is a Cenomanian genus and all these forms were extinguished at the Cenomanian/Turonian boundary, or thereabouts (Philip, 1982) and the Campanian-Maastrichtian forms are from a fresh radiation. Böhm's *Schiosia bilinguis* is a large specimen of *Sabinia klinghardti* (Skelton, pers. comm.).

The Bulgarian *Dessia* is named from one specimen so poorly preserved it could be anything and most of the canals seem to be borings.

Apart from *Coralliochama* the New world canaliculate forms are mostly included in the family Antillocaprinidae and include *Antillocaprina* and *Titanosarcolites* and I have no information which questions the validity of these species.

Summary of informal taxonomic amendments

Name in chapter 4	Name in chapter 6
Hippuritidae	
Hippurites nabresinensis	*Hippuritella lapeirousei*
Pironaea several species	*Pironaea* sp. div.
Yvaniella maestrichtiensis	*Hippuritella* cf. *bulgarica* ?
Yvaniella alpani	*Hippuritella/Hippurites* sp.
Radiolitidae	
Agriopleura (Maastrichtian Pyrenean species)	*Bournonia*
Apulites	*Bournonia*
Balabania	cf.*Colveraia*
Bournonia several species from Slovenia	*Bournonia* sp. div.
Bournonia several species from Croatia	*Bournonia* sp. div.
Bournonia several species from Bulgaria	*Biradiolites* sp. & *Bournonia* sp.
Biradiolites ingens from Bulgaria	*Bournonia* sp.
Branislavia	*Colveraia*
Batolites sp. from Bulgaria	*Hippurites* sp.?
Bystrickya	*Praeradiolites* sp.
Colveraia secunda	*Colveraia variabilis*
Darandeella	*Biradiolites* sp.*?lameracensis*
Distefanella minima	*Bournonia* sp.
Duranddelgaia	*Pseudopolyconites*
Fossulites from Slovenia	*Sauvagesia*
Eoradiolites sp. from Sicily	*?*
Joufia silvaeregis	*Joufia reticulata*
Klinghardtites musculosus	*Colveraia variabilis*
Kuehnia	*Radiolitella (Kuehnia)*
Kurtinia	cf.*Colveraia*
Lapeirousella	*Lapeirousia*
Lascarevia lamellosa	*Praeradiolites* sp.
Medeella	*Sauvagesia (Medeella)*
Milovanovicia	*Biradiolites*
Miseia	*Sauvagesia*
"one-banded monster"	*?Radiolites* nov. subgen.
Petkovicia	*Biradiolites*
Pseudokuehnia	*Radiolitella (Pseudokuehnia)*
Pseudopolyconites several species	*Pseudopolyconites* sp div.
Sphaeulites solutus	*?Biradiolites* sp.
Radiolites pasani	*Pseudopolyconites* sp.
Radiolites pseudomonopleura	*Bournonia* sp.
Rajka spinosa	*Biradiolites orbignyi*
Rosellia xavieri	*Praeradiolites* sp.
Vautrinia	*Osculigera*
Others	
Dessia	*?*
Gyropleura of Slovenia	*Apricardia*
Neoradiolites matheroni	cf.*"Sabinia"*
Neoradiolites serbicus in Serbia	cf.*"Sabinia" klinghardti*
Neoradiolites serbicus in Bulgaria	*"Sabinia"* sp.
Paramonopleura from USSR (not listed)	*Gyropleura*
Schiosia in Bulgaria	*?*
Schiosia bilinguis from Turkey (not listed)	*Sabinia klinghardti*

Chapter 4: Dating with Stontium-isotopes

This chapter seeks to introduce, explain and apply a method of dating marine sedimentary rocks which relies on the preservation of the ratio of $^{87}Sr/^{86}Sr$ present in the seawater at the time of formation of the sediment. The first section, 4.1 lays down the basic premises upon which the method is based and reviews the potential problems of this dating method, dismissing some, and outlining others which are of significance. A detailed discussion of these factors and an assessment of the accuracy and precision of this dating method forms section 4.2. The last two sections present my results; section 4.3 deals with the construction of a new Sr isotope curve for the Santonian-Maastrichtian, based on the Boreal stratigraphy; section 4.4 uses this curve is used to date certain Tethyan rudist samples.

4.1 Introduction to Sr isotope stratigraphy

4.1.1 The basic premises

1. The $^{87}Sr/^{86}Sr$ isotope ratio in the world's oceans today is essentially homogenous, and that has also been the case at every other moment in geological time.

2. The marine Sr isotope ratio is recorded in marine precipitates such as biogenic carbonate or phosphate.

3. That ratio has varied through geological time.

4. If it is known how the ratio has changed through time, then by measuring the $^{87}Sr/^{86}Sr$ ratio of the unknown sample and comparing it to a standard graph of $^{87}Sr/^{86}Sr$ change through time, the age of that sample can be established.

The method is based on properties of the geochemical cycle of the element strontium (described in detail in Elderfield, 1986). Natural Sr exists as four main isotopes, three stable isotopes, ^{84}Sr, ^{86}Sr, and ^{88}Sr and the radiogenic ^{87}Sr, which is derived from ^{87}Rb. In the formation of new crustal material, granites include more Rb relative to Sr than do basalts, so that the granitic continental crust has a higher $^{87}Rb/^{86}Sr$ and therefore evolves a higher

$^{87}Sr/^{86}Sr$ ratio than does the basaltic oceanic crust. Sr entering the marine reservoir is influenced by both these sources, by rivers eroding granitic crust and by hydrothermal recycling at oceanic ridges. The histogram (fig. 4/1) shows the $^{87}Sr/^{86}Sr$ ratio of these different sources at the present day; seawater is intermediate between granitic and basaltic values, and river water intermediate between seawater and the granitic value. It is the change in the relative contribution of these incoming fluxes which has caused the seawater ratio to vary through time (see fig. 4/2 from Burke *et al.*, 1985). Carbonates, bearing the seawater ratio are the main sink of Sr from the ocean and carbonate recycling, to some extent, buffers the rate of change of the seawater ratio.

Sr in the oceans has a relatively long residence time (around 4×10^6 yrs), that is the time it takes for Sr to complete the geochemical cycle of erosion and deposition into and out of the oceans (or, more precisely, it is calculated by the flux of Sr leaving or entering the oceans divided by the concentration of Sr in the ocean). This is much longer than it takes for the seawater of all the worlds oceans to mix (around 4000-5000yrs) so the $^{87}Sr/^{86}Sr$ ratio of the oceans is essentially homogeneous. Moreover, the amount of Sr which enters the sea in river water is two orders of magnitude lower (60ppb according to Goldstein & Jacobsen, 1987) than that already present in seawater (7.7 ppm). This causes most marine coastal environments to have waters with the marine Sr isotope ratio and can be demonstrated in the $^{87}Sr/^{86}Sr$ of shallow marine bivalves (see fig. 4/3), which also yield the marine ratio. Even the present day Mediterranean, which is anomalous in many geochemical properties, notably salinity, has the marine $^{87}Sr/^{86}Sr$ ratio.

4.1.2 Potential problems with the method

The usefulness of the method depends on an ability to measure the $^{87}Sr/^{86}Sr$ ratio from the sediment which represents the value of seawater from the time the sediment was deposited. For this to be the case, several criteria must be satisfied: a) that the sediment formed in water which bore the marine $^{87}Sr/^{86}Sr$ signature; b) the final $^{87}Sr/^{86}Sr$ ratio has not been affected by fractionation which might have occurred either during incorporation of Sr into the mineral or in the mass spectrometer; c) the original seawater ratio has been preserved in the mineral

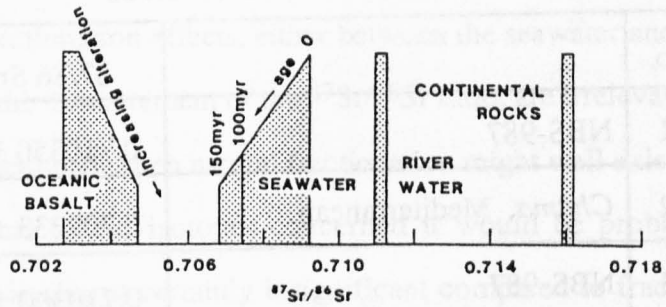


Figure 4/1. Histogram of the 87Sr/86Sr ratios of sea water and its sources. From Elderfield 1986.

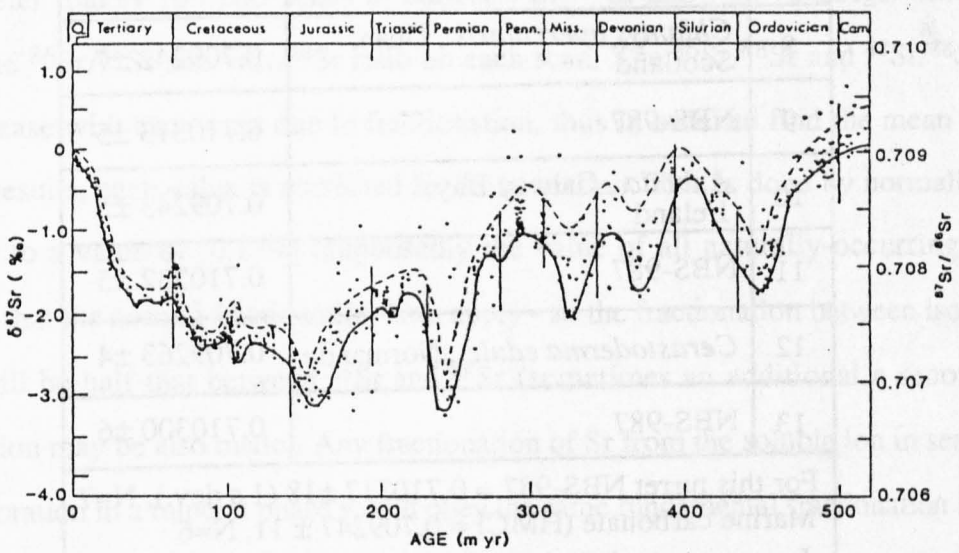


Figure 4/2. Variations in the 87Sr/86Sr ratio of sea water through Phanerozoic time. Modified from Burke *et al.*, 1982 by Elderfield, 1986.

Results for turret no. 652 with alternate NBS standards and modern marine bivalves		
No.		87/86 Sr
1	NBS-987	0.710350 ±8
2	*Chama*, Mediterranean	0.709233 ±8
3	NBS-987	0.710300 ±5
4	*Spondylus*, Pacific	0.709245 ±5
5	NBS-987	0.710307 ±6
6	*Lopha*, Pacific atoll	0.709257 ±4
7	NBS-987	0.710319 ±4
8	*Chlamys opercularis* , Oban, Scotland	0.709242 ±7
9	NBS-987	0.710313 ±5
10	*Anomia* , Galway Bay, Ireland	0.709243 ±5
11	NBS-987	0.710332 ±5
12	*Cerastoderma edule* , Normandy	0.709263 ±4
13	NBS-987	0.710300 ±6
For this turret NBS-987 = 0.710317 ±18 (1 s dev.), N=7 Marine carbonate (HMC) = 0.709247 ± 11, N=6 Long term variation NBS-987 = 0.710319 ±20 therefore marine carbonate = 0.709158		

Figure 4/3

and was not affected by later Sr-bearing fluids; d) that the mineral was not contaminated by newly Rb-derived ^{87}Sr on dissolution.

As discussed above, the first of these is unlikely to be a problem as only extremely near-shore restricted environments (which can be identified using sedimentological evidence), or those which lay near to the ridge axis, are likely to be out of equilibrium with the marine Sr ratio.

Mass-dependent fractionation effects, either between the seawater and incorporation in the mineral, or during the measurement of the $^{87}Sr/^{86}Sr$ ratio, are irrelevant because of the way the final ratio is calculated. Such natural fractionation might well exist - although given the high atomic weights of the isotopes concerned it would be probably too small to be measurable. Yet it is almost certainly insignificant compared to fractionation in the mass spectrometer when the relative isotopic abundances are measured. During that process the Sr evaporates from a heated filament, the lighter isotope evaporating more rapidly than the heavier. In measuring any one sample (which usually takes around three quarters of an hour when the machine operates in static mode - see later under section 4.3.3) the mass spectrometer makes 100-200 scans to collect ^{88}Sr, ^{87}Sr and ^{86}Sr (amongst others) and records the $^{86}Sr/^{88}Sr$ and $^{87}Sr/^{88}Sr$ ratio on each scan. The $^{86}Sr/^{88}Sr$ and $^{87}Sr/^{88}Sr$ ratios both decrease with each scan due to fractionation, thus in order to find the mean of those 100-200 results, each value is corrected for fractionation. This is done by normalising the $^{86}Sr/^{88}Sr$ to a value of 0.1194 (supposedly the value of all naturally-occurring Sr) and assuming that the normal fractionation laws apply - so the fractionation between isotopes 87 and 88 will be half that between ^{86}Sr and ^{88}Sr (sometimes an additional a second order fractionation may be also made). Any fractionation of Sr from the soluble ion in seawater to its incorporation in a mineral phase would obey the same fundamental fractionation law; thus no relative increases in ^{86}Sr and ^{88}Sr in the seawater or carbonate can be measured once values have been normalised. It is only the independent variation in the amount of ^{87}Sr, which is provided by ^{87}Rb decay, which can be detected.

Contamination and alteration influence the type of material chosen for measurement of the $^{87}Sr/^{86}Sr$ ratio. Several minerals will incorporate Sr and thus could potentially be used for dating, though carbonate has the advantage that it only incorporates Sr originally and not Rb, so that there should have been no growth in the ratio due to Rb decay since the mineral was formed. This is not the case for other mineral phases, (notably clay minerals and possibly not for phosphate either - D. Cummins, Cambridge, pers. comm., 1989) which could be used, but would require the subtraction of the amount of newly-formed ^{87}Sr from the measured $^{87}Sr/^{86}Sr$ ratio, and so would be much more complicated to use. For this reason this discussion is only concerned with carbonate samples.

The carbonate must be dissolved without contamination by these Rb-bearing phases. Fortunately, laboratory contamination of the sample due to unclean utensils etc. is not a significant factor. Most calcite contains several hundred ppm Sr and sample size is generally of the order of tens of mg so any contamination usually accounts for far less than 0.01% of the sample (see blanks under methodology, section 4.3.2). Contamination can occur through during dissolution of a sample when the sediment components cannot be separated manually. This is discussed in detail under section 4.2.1

Carbonate has the great disadvantage (compared to phosphate) of altering its $^{87}Sr/^{86}Sr$ by exchange with the external environment during diagenesis. Various techniques can be used to detect samples which are severly altered and these can be excluded from the analyses. The extent to which slightly altered samples can be used (and most samples will be slightly altered) is a matter for debate and this is reported in section 4.2.2

Finally, the $^{87}Sr/^{86}Sr$ value obtained from undiagenetically altered or otherwise uncontaminated calcite will reflect the value of the $^{87}Sr/^{86}Sr$ at the time of precipitation of the mineral. Thus if the carbonate is reworked, it will not reflect the age of the final sediment deposition.

When the $^{87}Sr/^{86}Sr$ ratio of the sediment, thought to be that of the seawater at the time of its deposition, has been measured, the result must be related to a standard curve. For dating

isolated samples, or those penecontemporaneous, the age must be known roughly, so that the relevant portion of the Sr isotope curve can be used. Moreover, given that rough age constraint, the graph must show a regular trend - upwards or downwards, but not both, and the curve must be smooth, without additional high frequency "noise". The precision of dating will then depend on the precision of analysis of $^{87}Sr/^{86}Sr$ in the sample, the precision of the reference curve and on the rate of change of $^{87}Sr/^{86}Sr$ with time over that given period. For dating a series of samples, the precision will be greater because the pattern of $^{87}Sr/^{86}Sr$ obtained from those samples can be matched to a portion of the standard curve (given some knowledge of the sedimentation rate). The data available for the definition of the curve in the Late Cretaceous is presented in section 4.2.3 and possible precision in dating discussed in section 4.2.4.

4.2 Accuracy and precision for dating Cretaceous samples

4.2.1 Contamination by non-carbonate material

The first stage in separation of the carbonate from non-carbonate phases is manual and involves cutting, or otherwise separating, the requisite piece of carbonate from the rock and removing any weathered exterior - a method which may be quite satisfactory for macrofossil samples. Yet there are other sample types, such as bivalves which trap detrital material between the growth laminae, or bulk sediment samples, where the phases are physically inseparable and chemical methods must be used. In the studies tabulated in figure 4/4 this chemical separation has been restricted to the method of dissolution. Stronger acids, such as 2.5*N* HCl or even weak HNO_3 should not be used for these types of material because these acids may liberate non-carbonate radiogenic Sr from Rb-containing phases, particularly the Sr held loosely at the edges of clay minerals. In my opinion there also some risk of contamination with 0.25*N* HCl and possibly 5*N* acetic acid. In the future samples may first be washed with buffered ammonium chloride to alliveate the problem (Kastner & Elderfield, in prep.). The reason that the stronger acids are used is that dissolution is immediate and samples can be loaded directly onto ion-exchange columns without evaporation and redissolution.

Reference	Location	Leg/Site	Biostratigraphic age	No.	Sample type	Dissolution	Screening for diagenesis	standard values and quoted precision
Burke et al., 1982	Central Pacific	17/167	Camp.	6	bulk sediment	1 M HCl or	rejection of samples	NBS-987=0.71014
		22/216	U. Maas.	1	<10% acid I.R.	1M HNO3	Sr content <200ppm	HMC (B)=0.70907 ± 0.000040 (1 std. dev.), N=41
	Denmark, Stevns' Klint	-	U. Maas.	1				E&A=0.70797±0.000030 (1 std. dev.)
	Netherlands	-	U. Maas.	5				precision for samples 0.000050 (2 std. devs.)
	Iran	-	Sant.-L. Maas.	13				
	USA	-	Sant.-U. Maas.	16				
DePaolo & Ingram, 1985	North Pacific	62/465a	L. Pal.	3	bulk sediment	5M acetic acid	generally no obvious	HMC (DP&I)=0.709234±0.000018 (2 std. devs.), N=18
	Denmark		L. Pal.	1	whole brachiopod	warm	cementation under SEM	NBS-987=0.71031
Palmer & Elderfield, 1985	South Atlantic	3/21*	Maas.(?)	3	picked foraminifera	unspec.	generally seemed unrecrystallised under SEM	HMC (P&E)=0.709238 ± 0.000026 (2 sigma), N=24 NBS-987=0.710275 E&A=0.708066
Hess et al., 1986	North Pacific	32/365	Sant.-Maas	16	picked foraminifera	2.5M HCl	samples checked under SEM	SW=0.709198±0.000020 (1 std. dev.)
	South Atlantic	39/356	U. Maas.	1	whole tests >150µm		those from 305 &356	NBS-987=0.710220
	North Pacific	86/577	L. Pal.	1			were visibly altered	E&A=0.70800
							rejection of samples	general precision ±0.000020 - 30
							low Sr-content	
							measurement of 87/86Sr of pore waters	
Jones et al., 1987	Braggs, Alabama, USA	-	U. Maas.	6	large bivalves (chiefly oysters). samples from middle shell layers. also picked forams?	unspec.	oysters inspected in t.s. for diagenesis. Samples with same stable isotope constitution as sediment foraminifera with overgrowths and recrystallisation avoided	NBS-987=0.71023
McArthur et al., in press	borehole Norfolk, England		Cen.-mid. Maas.		uncemented chalk		seemed friable and unrecrystallised	NBS-987=0.710240
Turpin et al., in press	Stevns Klint, Denmark		U. Camp.-L.Pal.		bulk sediment	5M Acetic		NBS-987=0.71027
	Bidart, France		U. Maas.-L.Pal.		bulk sediment			
	Sopelana, Spain		U. Maas.-L.Pal.		bulk sediment			
	Caravaca, Spain		U. Maas.-L.Pal.		bulk sediment			
Swinburne, this work	northern Europe		Sant.-Maas.	12	belemnites	2.5M HCl	Sr-content of belemnites always high	NBS-987=0.710230 1std dev. = 20
				2	uncemented chalk	5M Acetic		HMC = 0.709158 1 std dev. = 13 n= 6
	Kronsmoor/Hemmoor		Maas.	4	belemnites	2.5M HCl		
				11	uncemented chalk	5M Acetic		

Figure 4/4. Tabulation of data sets of Upper Cretaceous and lowermost Palaeocene Sr isotope values.

It should be possible to detect gross contamination by measuring the concentrations of certain trace elements in the solution, for example Al, Mn and Fe. This was done for many of the samples in this study (but there were problems with the method chosen for their measurement -see later under results). In practice small amounts of contamination cannot be distinguished from the original variation in concentration of these elements in calcite, or from small amounts of diagenetic alteration.

4.2.2 Diagenesis and methods of sample screening

It is an intrinsic property of the element Sr that the original $^{87}Sr/^{86}Sr$ ratio tends to be preserved despite minor diagenesis of the carbonate which may have affected the Sr concentation. [The theory of repartitioning of trace elements is amply discussed in the works of Veizer (e.g. Brand & Veizer, 1980, 81, Veizer *et al.*, 1983a, 83b) and will only be summarised extremely briefly here.] Shells secreted by living organisms from calcium carbonate are made of two mineral structures, aragonite and calcite. These vary greatly in their trace element constitution. The highest concentration of any trace element is that of magnesium and it is used to define two varieties of calcite (actually end members of a spectrum), high-Mg and low-Mg calcite. Sr is also at relatively high concentrations in calcium carbonate, with aragonite having a much higher concentration of Sr than calcite. Additionally, high-Mg calcite has more Sr than low-Mg calcite and organically-precipitated calcite more than inorganically-precipitated types.

Under diagenesis, the different forms of calcium carbonate alter to varying degrees. Aragonite and high-Mg calcite are metastable, recrystallise to calcite and expel the excess Sr to the pore waters. Low-Mg calcite, though stable under surface conditions of temperature and pressure, will still start to exchange ions when bathed in pore waters of different constitution, such as meteoric water. Thus the overall tendency is for the original Sr to be expelled into the pore waters. If these waters remain within the rock ("closed diagenetic system") then Sr concentrations build up and cements precipitated bear the original marine ratio. If though the waters are flushed through the rock ("open diagenetic system") then Sr is

leached from the rock. In both cases the original marine ratio tends to be preserved in the rock.

Unfortunately this is something of an oversimplification. The sediment is a complex system and the pore waters are not in complete communication (when considered at the time scale of dissolution/precipitation of the calcite). Locally calcite may be affected by pore waters which have aquired a foreign $^{87}Sr/^{86}Sr$ ratio. However, the same effect tends to cause larger fragments to act as their own closed diagenetic systems and merely redistribute the Sr. There may be many stages of diagenesis with pore waters of different origin and chemical constitution. In later diagenesis, if the sediment is buried, Sr may be liberated by the breakdown of previously stable sediment components and be incorporated in the calcite as the distribution coefficients change at higher T & P.

Various screening techniques have been adopted by investigators to detect diagenetically altered samples. Firstly there are visible criteria. Macrofossil samples can be sectioned and viewed through cross-polars. In rudist bivalves, the calcitic layer is made of a structure of fibrous prisms. In unaltered material these extinguish at slightly different orientations of the stage and as the stage is rotated the black colour sweeps across the piece of calcite (figured in Al-Aasm & Veizer, 1986a). When this material undergoes diagenesis, the fibres coalesce into large units eventually resulting in large, single-crystal fields. Microfossils may be examined under the SEM to check for surface alteration and overgrowths.

Visible criteria, though easy to use, are regrettably not very satisfactory in detecting samples where the $^{87}Sr/^{86}Sr$ is altered. This is because the extent of visible disruption is highly dependent upon the speed of alteration. Very slow alteration could have altered the geochemical constitution but have had little or no effect upon the texture. It may therefore be better to use a geochemical criterion, such as Fe, Mn concentration for diagnosing diagenetic alteration. Fe and Mn have a partitioning history during diagenesis which is the opposite of Sr. They tend to be introduced into the pore waters from dissolving Fe minerals in the sediment and may be at relatively high concentrations in meteoric waters. They are also preferentially incorporated in the precipitating calcite and therefore tend to be at higher

concentrations in diagenetic than original calcite. There is also (as already mentioned) some variation in concentration of these elements between different types of calcite but diagenetic alteration causes variation one or several orders of magnitude greater. Fe and Mn concentrations can be assessed by staining the rock with alizarin red S and potassium ferricyanide or by examining by cathodoluminescence. The staining is intended to show those parts of the shell with late Fe-rich cements and the cathodoluminesence areas rich in Mn (but low in Fe). Fe and Mn may also be measured directly from solution of the sample.

There is some point too in measuring the Sr concentration to eliminate samples which have very low Sr contents and are clearly altered in some way. However it is impossible to give one value of Sr concentration below which samples should be rejected as "altered". Firstly, calcites of different biological origin have different initial Sr concentrations. Secondly some Sr is exchanged more readily than the rest. This is because the Sr is incorporated in a variety of ways into the $CaCO_3$ shell; Most replaces the similarly-sized and charged Ca ion where it may be exchanged relatively easily during diagenesic dissolution-precipitation. As already discussed, the concentration of this Sr may decrease, increase, or more likely follow some complex intermediate path. Some Sr is bound to the organic matrix of the shell and this is far less easily detached. For instance, I have found particularly high Sr concentrations in types of organic-rich calcite, notably requienid rudists which consistently gave values of around 1200ppm and belemnites around 1500ppm. Even when the fabric of this calcite appears neomorphosed the high Sr content persists making these excellent samples for Sr isotope analysis. A third complicating factor in considering the absolute Sr-content as an indicator of diagenesis is that the concentration of Sr in the worlds' oceans has changed through time, as demonstrated in the Sr/Ca ratio of unrecrystallised foraminifera by Graham *et al.* (1982) for the Cenozoic and Delaney (1983) for the Late Cretaceous. Thus although a value of 800ppm is a rough guide to the Sr content of the foraminiferal low-Mg calcite of the Late Cretaceous, this can vary by around ±150ppm. Using this work, Hess *et al.* (1986) excluded those foraminifers from their study which had Sr contents significantly below the value for contemporaneous foraminifers found by Delaney.

Using these techniques for detecting diagenesis all authors agree that highly altered and replaced samples should be excluded, but there is no consensus of opinion in the extent to which slightly altered samples should be used. An example of the greatest caution involving the most elaborate screening techniques comes from the work of Popp *et al.*, (1986) on Carboniferous brachiopods. The shells were sectioned, and both stained and examined under cathodoluminesence. A sample was drilled from a non-luminescent and stained portion of the shell, which was then repolished and reexamined to check again for alteration. The selected samples were dissolved and the trace element contents and stable isotope ratios measured. Results showed that these apparently unaltered samples had very similar trace element concentrations and stable isotope results, compared to results for entire shells (which included altered portions), which showed much greater variation. As expected, the $^{87}Sr/^{86}Sr$ results from the selected "pristine" areas produced a narrow spread of results about a mean, which were the same to within machine precision. However, somewhat less expectedly, results for the whole shells (which contained altered and pristine areas) produced the same mean with equally tight precision as results from the pristine areas (whilst those of the external sediment were more radiogenic). So in effect, had the study been only to establish the seawater Sr isotope value of the shells (which it was not), the whole time-consuming procedure would have been unneccessary. More distressing than this apparently wasted effort is the indication that even this thorough screening process is not fail-safe. For example, Popp *et al.* also cited a study of some brachiopods from Algeria where the non-luminescent portions had a much wider spread of $^{87}Sr/^{86}Sr$ values than simply due to machine precision. In the absence of any other reason they suggested that inhomogeneity of seawater might be to blame.

Finally in considering the likely effects of diagenesis it is worthwhile studying the general diagenetic history of the sediment. Fortunately, most Cretaceous samples have never been deeply buried in comparison with Carboniferous samples discussed above, and alteration has been at near surface temperatures and pressures. For example, most of the shallow marine carbonate sequences of Cretaceous age now outcropping on land were uplifted from the sea by alpine tectonics, possibly as long ago as Palaeogene times. Thus for most of their

late diagenetic history when any replacement of Sr is most likely to effect a change in the $^{87}Sr/^{86}Sr$ ratio, they have been bathed in meteoric water. Meteoric water will usually have picked up the value of overlying, carbonates (which, if younger would have a higher $^{87}Sr/^{86}Sr$ ratio) or, (if none are present), will have been influenced by radiogenic Sr from granites or clays with higher $^{87}Sr/^{86}Sr$ ratio. Diagenesis of many land-based sequences thus tends to cause values to be displaced upwards to more radiogenic values.

4.2.3 The Sr isotope curve in the latest Cretaceous

Figures 4/6 & 7 show the two main sets of $^{87}Sr/^{86}Sr$ data for the Late Cretaceous, that of Burke *et al.* (1982) (from the data tabulated in Koepnick *et al.*, 1985) and Hess *et al.* (1986). The values for the data points are listed in the appendix and the types of samples used and their dissolution procedure are tabulated in figure 4/4. In comparing the graphs it can be seen that the Burke data shows a greater scatter, which was probably due to inferior machine precision and stratigraphic age assignment (particularly of the land-based samples). There is also a tendency in the latest Cretaceous, and other portions of the Burke curve, towards certain high blips. These were mostly caused by contamination with non-carbonate, Rb-derived Sr, due to the acids which they used for dissolution of the bulk carbonate samples, together with lesser effects due to diagenesis. The Hess data also show considerable scatter in the Cretaceous, though the Cenozoic portion of the curve was much more tightly constrained. This is because the Cretaceous samples, which nearly all came from site 305, were diagenetically altered because they were visibly cemented on the surface.

However, overall the graphs show that the latest Cretaceous (Coniacian-Maastrichtian) was a time of rapid $^{87}Sr/^{86}Sr$ change (around 2.1×10^{-5} per m.y.) and therefore potentially useful in dating samples known to be roughly of that age. This is in contrast to the middle Cretaceous where the curve is almost flat (McArthur *et al.*, in prep.). Given the scatter of the points, it is not possible to know the exact shape of the curve. Conceivably the scatter could be real - demonstrating either original inhomogeneity in Late Cretaceous seawater, or variation on a short time scale - though given the smooth nature of the curves now

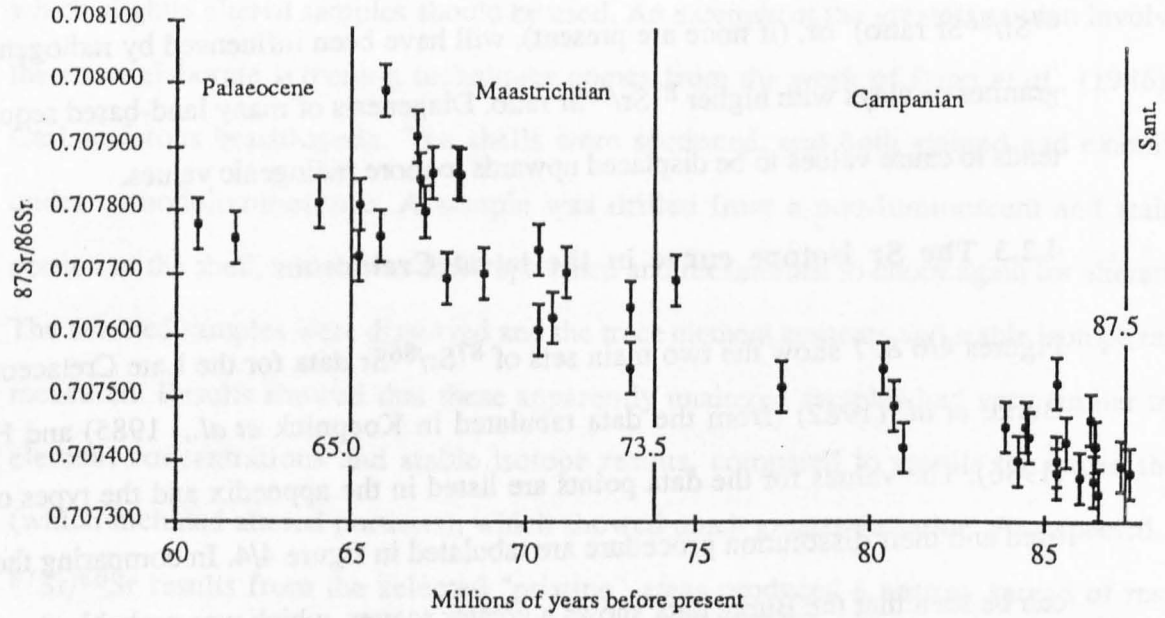


Figure 4/5. 87Sr/86Sr variation against time in m.y. Error bars show ±2 Std Devs. of their standard. From the data in Koepnick *et al.*, 1985, plotted in Burke *et al.*, 1982

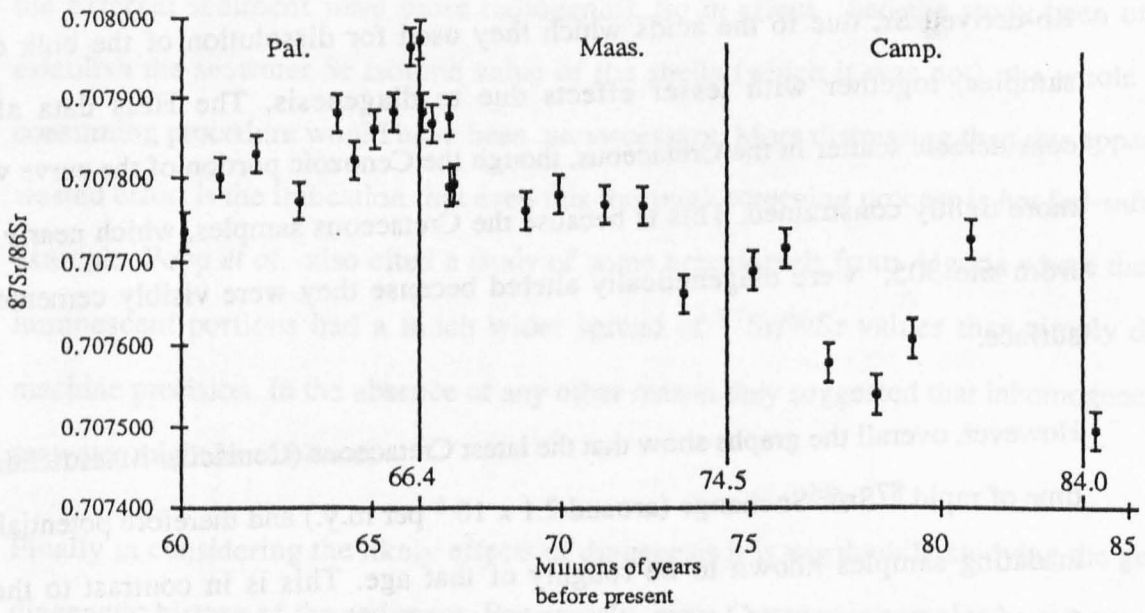


Figure 4/6. 87Sr/86Sr variation against time in m.y. .Error bars show ±2 Std Devs. of their standard. From data of Hess *et al.*, 1986

established for the Cenozoic (eg. Hess *et al.*, 1986, DePaolo & Ingram, 1985), this seems highly unlikely. If the pattern were linear a best fit line could be drawn through the points and the error calculated from the deviation of points from the line - but this should not be assumed *a priori*.. The graph could instead consist of numerous portions of steeper rises punctuated by plateaux (shown for the Neogene by DePaolo & Ingram, 1985, a pattern they relate to transgressions and regressions). However as a first approximation it is not unreasonable to draw a straight line through the data points for the latest Cretaceous and I have done this for the Hess graph and in order to read the $^{87}Sr/^{86}Sr$ values for the stage boundaries, (though the substantial errors on these values - of the order of ±50 in this are clear from the diagram).

Some authors (such as Elderfield, 1988) favour the compilation of all these data points (and others from studies, tabulated in figure 4/4) for tighter constraint upon the line, but this is not an approach which I advocate. Firstly it assumes the pattern is a straight line (which may not be the case), but secondly, even accepting this as an approximation, it could lead to the compounding of errors inherent in the construction of each data set. As regards the errors in the $^{87}Sr/^{86}Sr$ axis, it is not desirable to use one standard data set from another laboratory to date unknown samples without a variety of common standards (see later under section 4.3.4). Moreover, in combining different studies, the $^{87}Sr/^{86}Sr$ values for each data set are not equally reliable as the analyses were made using different material, each subject to its own trends of contaminiation and diagenesis.

Mixing data sets may also compound errors in the other axis, the age assignment of the samples. It can be extremely difficult to assign a numerical age to Cretaceous samples and so although the relative ages of samples in any one study is useful, an absolute comparison between different studies can introduce large errors. It would have been far more useful for different investigators to have stated the biostratigraphic assignment of the samples. To demonstrate the futility of comparison of the absolute age assignment it is worth explaining how they are calculated. Very few Cretaceous cores have reliable magnetostratigraphy and instead the fixed datums are certain foraminiferal and nannofossil zonal boundaries (mostly stage boundaries). These datums must be correlated to places where radiometric dates have

been obtained. The best dates for Late Cretaceous strata come from the U.S. Western Interior from bentonite layers (Kennedy, 1989). The sequence is zoned using ammonites which are mostly American endemics, so the correlation with the equatorial microplankton stratigraphies is indirect (via the Gulf coast). Far more dubious tie points have been used throughout the years, mostly glauconite-derived ages (see Obradovich, 1988 for problems with these data) and as such the age estimates for these datums have changes substantially over the years (see figure 4/5).

The combination of the Burke and Hess data sets is an excellent example of the misleading effects that can result if data sets are simply combined. For example, Elderfield (1986) in adding one set to the other produced a large spike around the K/T boundary, which may not exist at all, or if it does has been greatly exaggerated. The Burke data show several anomalously high values from Cretaceous samples which are probably due to contamination or diagenesis, as discussed above. These samples were assigned ages of 66-67 m.y. some 2-3 m.y. older than that of the K/T boundary at 65 m.y. (using the Harland *et al.*, 1982 timescale). The Hess data show a spike after the boundary from two high data points from Palaeocene samples (which may, or may not be truely representative of the seawater ratio). These plot also plot at 66.2-66.3 m.y., with the K/T boundary at 66.4 (using the Berggren *et al.*, 1985 timescale).

4.2.4 Machine precision compared with homogeneity of $^{87}Sr/^{86}Sr$ in seawater.

The precision currently obtainable on the most advanced mass spectrometers is such that no inhomogeneity in modern seawater can be detected. This is also shown in measurements of modern marine carbonate which are essentially the same (see fig. 4/3 for measurements of a selection of ecologically diverse modern bivalves). As modern marine carbonate may reflect 2000 years of deposition or more this is encouraging as it seems to imply that variations of the marine reservoir on a time scale of less that that of mixing of the oceans (around 4-5000 years) are negligible.

Table of some numerical dates for Cretaceous stage boundaries in the more commonly used time scales

Harland *et al.*, 1965	Van Hinte, 1976	Harland *et al.*, 1982 (used by Burke *et al.*, 1982)	Berggren *et al.*, 1985 (used by Hess *et al.*, 1985)
65	65	65	66.5
Maastrichtian	Maastrichtian	Maastrichtian	Maastrichtian
70	70	73	74.5
Campanian	Campanian	Campanian	Campanian
76	78	83	84
Santonian	Santonian	Santonian	Santonian
82	82	87.5	87.5

Figure 4/7. Table of some numerical dates for Cretaceous stage boundaries in the more commonly used time scales.

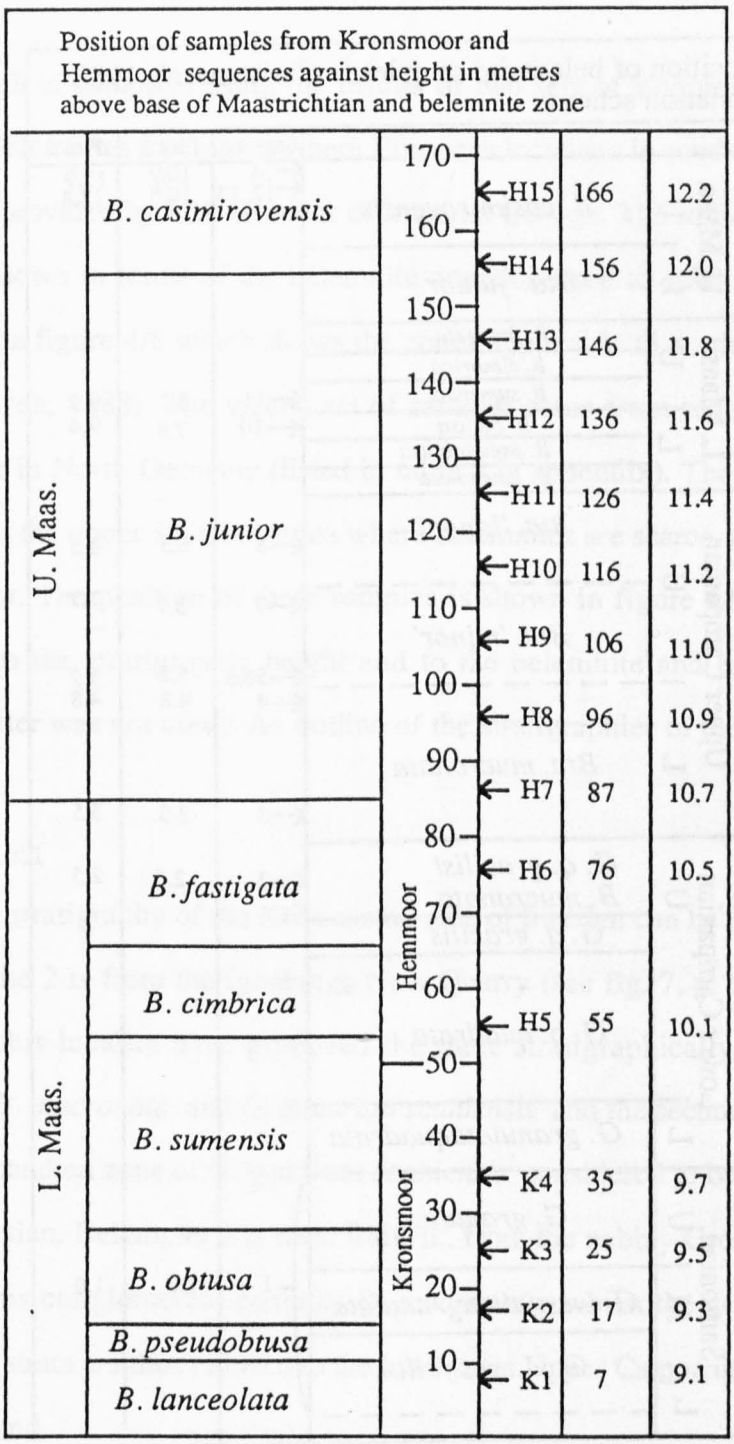
The precision with which the Sr isotope ratio of palaeo-seawater (as preserved in uncontaminated, unaltered, marine carbonate) can be measured is therefore dependent upon the precision of the mass spectrometer. Machine precision is usually calculated from the long term standard deviation of a Sr standard which is usually run in each turret of samples (a "turret" being the holder with the batch of samples to be analysed during one run of the mass spectrometer). The conventionally-used standards are: NBS SRM-987 $SrCO_3$, Eimer & Amend $SrCO_3$, a vial of modern seawater, or a finely ground and mixed sample of modern carbonate (the two latter are now available in standard issue, but more usually they are home-preparerd). The standards are also necessary for the comparison of different data sets, the use of more than one being desireable as it may help compensate for minor interlaboratory differences (Elderfield, 1986).

There is unfortunately no general agreement between authors in the expression of errors on either the $^{87}Sr/^{86}Sr$ value, or the derived age, and it is frequently hard to understand how they have been calculated. In the tabulation of data sets in 4/4 the last column shows the value for the standards and their precision found by other authors of Cretaceous studies. Most of these values are standard deviations (2 std devs around ±40 on the last two of 6 figures), though the DePaolo values are standard errors. However, the errors shown on individual points on graphs in these and other studies may be some other quantity entirely. For instance, Mckenzie *et al.*, 1983 shows two standard deviations for a single run of a sample (usually ±20).

4.3 Construction of a new standard graph based on the Boreal stratigraphy

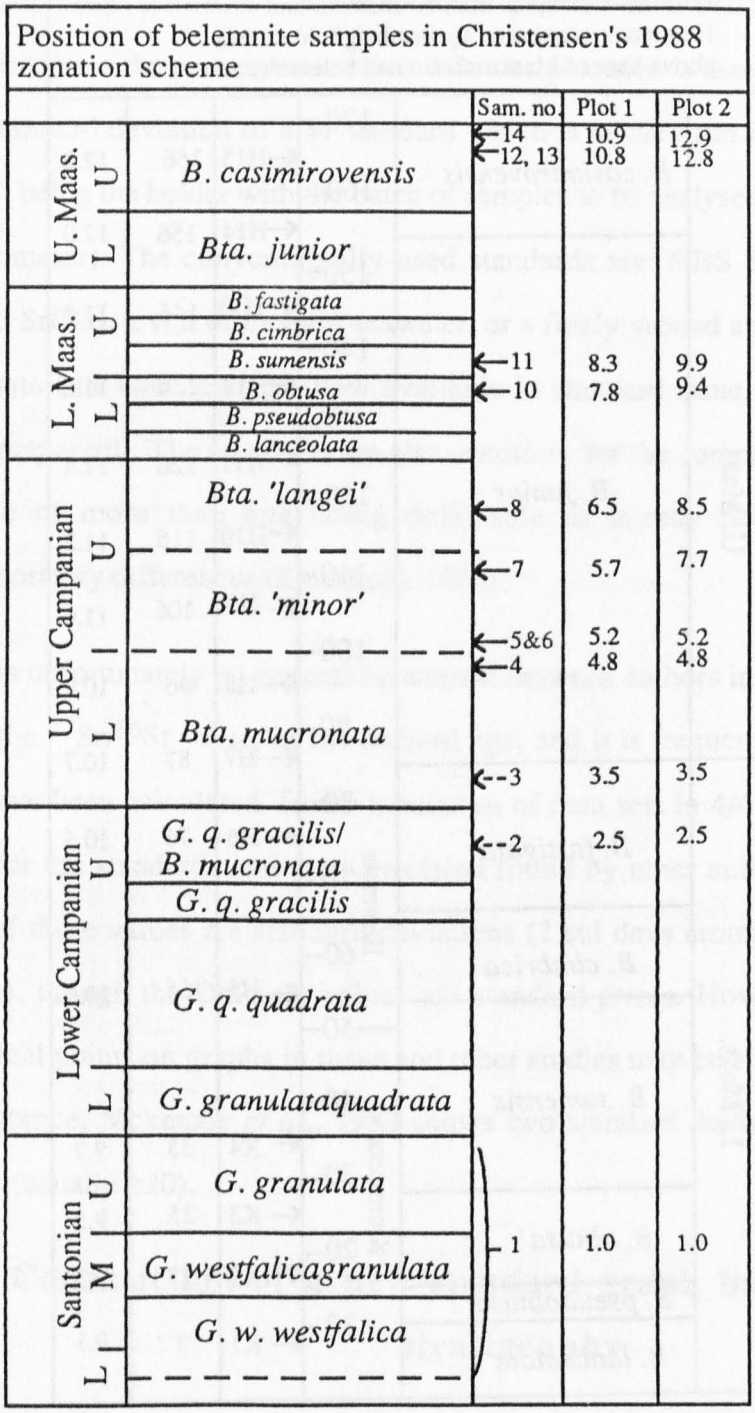
4.3.1 Provenance of samples

Given the imprecise nature of the standard data so far available for the Cretaceous part of the Sr isotope curve, and the problems of comparison with another laboratory's standard data set, it was necessary to construct another standard graph for the purposes of this study. Moreover, as the primary aim was to date samples of probable Maastrichtian age, I decided



Stratigraphy after Schulz & Schmidt, 1979

Figure 4/9



*Belemnites 2 & 3 are from Balto-Scandia correlated to the NW Europe stratigraphy using Christensen 1986

*2 Samples 13 & 14 are bulk carbonate

Bta. = *Belemnitella B.* = *Belemnella G.* = *Gonioteuthis*

The Lower Campanian-Maaastrichtian belemnites are plotted on a scale approximately that of this diagram which is reproduced exactly from Christensen's original. The Santonian belemnite (included merely for the purpose of defining the 87/86Sr value at the belemnite S/C boundary) is plotted an arbitrary one unit below the Lower Campanian belemnite.

Figure 4/8

to construct the graph from material from the Boreal province, where the type Maastrichtian sequence is situated.

The final graph is compiled using the results of two sets of samples. The first set was a collection of belemnites from the northern European localities in southern Sweden, England and Denmark provided by Jake Hancock of Imperial College. The stratigraphic level at these localities is known in terms of the belemnite zonation used to subdivide the Boreal Late Cretaceous (see figure 4/8 which shows the zones applicable to northern Europe, redrawn from Christensen, 1988). The second set of samples came from sequences at Kronsmoor and Hemmoor in North Germany (listed in table 2 in appendix). The lower 4 samples are belemnites and the upper 11, from strata where belemnites are scarce, are pure, uncemented chalk sediment. The position of these samples is shown in figure 4/9 and is known both with respect to the stratigraphic height and to the belemnite and brachiopod zonations (though the latter was not used). An outline of the stratigraphies of these localities is given below:

Southern Sweden

The belemnite stratigraphy of the Kristianstad area of Sweden can be found in Christensen, 1975. Belemnite 2 is from the Ignaberga New Quarry (see fig. 7, p. 11 in that reference). The strata at this locality have produced the three stratigraphically important forms *B. mammillatus, B. mucronata* and *G. quadrata scaniensis* and the section is therefore referred to the Balto-Scandian zone of *G. quadrata scaniensis* considered to be the upper part of the Lower Campanian. Belemnite 3 is from Balsvik, from the pebbly Greensand at the base of the quarry. This conglomerate contains *B. mucronata* whilst the genus *Gonioteuthis* is absent and the strata are thus referred to the lowermost Upper Campanian.

Norfolk, England

Upper Campanian and Maastrichtian strata are exposed around the Norfolk coast and a description of the localities can be found in Peake & Hancock, 1978. Belemnites 4, 5 & 6 are from the 'Weybourne' Chalk (see fig. 5, p. 315, in that work, which shows the notation given to the flint bands). Belemnites 5 & 6 are from the chalk around the stratigraphically adjacent flint bands Z & U which are in the base of the *minor* zone. Belemnite 4 is from

slightly below the base of that section in a unit referred to as the Weybourne gamma which is at the top of the *langei* zone (Hancock, pers. comm., 1989). Belemnite 7 is from the middle of 'Beeston Chalk', a unit which overlies the 'Weybourne Chalk'. The locality is described as "east of Ordon Gill" which places it near the top of the *minor* zone. Belemnite 8 was an erratic, though its location on the shore below Cromer lighthouse implied that it was almost certainly derived from the Paramoudra Chalk from which *B. langei* has been obtained. The unit contains numerous hardgrounds including one at the base of the unit. Belemnite 9 (not included on the plot) was of uncertain age. It was found loose on the *Pyramida* flint spread at Overstrand.

The Maastrichtian of Norfolk is known only from glacially disturbed blocks. Belemnite 10 came from Sidestrand between flint bands P & Q (see fig. 7, p 232 in Peake & Hancock, 1978). These are part of the Porosphaera beds which have produced *B. lanceolata.* Belemnite 11 came from the overlying unit of the sponge beds, as exposed at Trimmingham, at a level placed in the *sumensis* zone (Hancock, pers. comm., 1989).

Denmark

Belemnite 12 was supplied by Walter Christensen and came from the 'Dania' pit at Hadsund, near Mariager, Jylland (see Håkansson & Hansen, 1979 for information on this locality, noting especially fig. 13, p. 187). The Maastrichtian strata exposed in the quarry are all upper, Upper Maastrichtian falling within the last nannofossil (*Micula prinsii*), brachiopod (*stevensis/chitoniformis*) and belemnite (*casimirovensi* s) zones (see also Surlyk, 1984). Samples 13 & 14 were collected by Liz Harper of the Open University. 13 is a chalk sample from Holtug Quarry also in the last brachiopod and belemnite zones. Sample 14 is from Stevns Klint (see Surlyk, 1979 for a description of that locality, noting fig. 2, p 166). The sample is from a few metres below the fish clay.

Northern Germany

For sections at Hemmoor and Kronsmoor the reader is referred to Schulz *et al.,* 1984. At Kronsmoor the section is complete across the C/M boundary and continues into the *sumensis* zone of the Lower Maastrichtian. The Hemmoor section extends from a level equivalent to the top of the Kronsmoor section into the base of the *casimirovensis* zone of the upper, Upper Maastrichtian.

4.3.2 Sample extraction, dissolution and trace element analysis

Chips of belemnite calcite and of bulk sediment were extracted manually from the hand specimens using a hammer and small chisel. The chips were then scraped under the binocular microscope using a scalpel to remove any weathered surfaces. In the laboratory samples were cleaned with the same acid as used for dissolution. Samples for trace and minor element analysis were then dried and weighed, and in general sample weight was in the range 5-40mg. The belemnite samples were then dissolved 2.5*N* HCl acid for less than 10 minutes and the sediment samples in 5*N* acetic acid around 5 hours (and these were also sometimes slightly warmed to speed the process). The amount of acid was also varied so that the dilution factor was kept slightly over 1:100 for best results in trace element measurement. The solutions were then centrifuged and 2ml decanted off. In the case of samples dissolved in weak acids, this was then evaporated to dryness and redissolved in 2ml 2.5*N* HCl. One ml was kept aside and diluted 1:10 with water for trace and minor element measurements. The other was pipetted onto an ion-exchange column and separated in the usual manner. The Sr fraction was evaporated to dryness, then redissolved in a small amount of acid and transferred to a microbeaker.

Trace and minor elements were measured on a plasma source mass spectrometer at Surrey University (Plasmaquad). In retrospect it was a mistake to use this method because the interrun precision turned out to be so poor - particularly for Fe which could be up to 100% out between different runs - although Sr was more reliable. In fact the results have only been useful for demonstrating gross contamination in Fe, Mn and Al due to incorrect dissolution, as well as for providing rough figures for Sr-content. For these reasons the trace element results are not discussed in detail and are not tabulated in the appendix (with the exception of those from the first set of Spanish results).

4.3.3 87Sr/86Sr analysis on mass spectrometer

The dry sample was loaded onto an outgassed tantalum filament and Sr isotope ratios measured in a mass spectrometer at the Open University (Finnegan-MAT 261). Total blanks for the Sr isotope procedure averaged 2ng.

All Sr isotope results for the samples and standards are listed in the appendix. Two NBS standards were usually placed in each turret and ran at the beginning and end of each run of the mass spectrometer. The samples were run in two batches between which certain adjustments were made to the mass spectometer. Thus for those results prior to 19.5.90. (when Sr was collected in static mode - see below) the long term, laboratory average and precision for NBS-987 was 0.710230 ±20 (1 standard deviation). Average and precision has also been calculated separately for each set of sample analyses, from the standards placed in those turrets, and these values are recorded in the result tables in the appendix. From these it can be seen that the precision worsened through time and the average fell. However, using the results from the entire laboratory, though the same increase in variation was seen, the average stayed constant. Thus results obtained in the first batch, where standards in a particular turret were particularly low, I have not renormalised the values to 0.710230 but merely recognised the poorer precision on the final plot (see below). To increase the accuracy of the final $^{87}Sr/^{86}Sr$ value for a particular sample, it was loaded onto 2 or 3 separate filaments and was run in several different turrets and the average taken. (If the same sample is run several times on different filaments in the same turret, the result may be more precise, but less accurate). When the machine collected Sr dynamically there did not seem to be this inter-turret variation.

After the machine adjustment the NBS standard came to 0.710319±20 for long term precision and the bivalve standard 0.709247 ±13 (see fig. 4/3 for the results from running alternating NBS and marine carbonate standards in one turret). Comparing the value for these standards using the delta notation where:

$$\partial^{87}Sr\ (‰) = (^{87}Sr/^{86}Sr_{\ sample}/^{87}Sr/^{86}Sr_{standard} - 1) \times 1000$$

the bivalve standard is 1.51 less than the NBS-standard, which is in agreement with 3 out of 5 of the studies listed in Elderfield, 1986, table 3, p.74.

For this second set of results the mass spectometer collected Sr in dynamic mode where the different isotope beams are switched between collectors, so that any systematic bias in the collectors is cancelled out. The results for the Boreal samples are plotted in figures 4/10-12. In these figures and the later plots in figures 4/14-18 the quantity shown by the side of each graph is ± 2 standard deviations of the NBS-standard (usually ±40) (though it would perhaps have been more representative to have used marine carbonate as the primary standard because this is the same type of material as the samples and it seems to give more consistent interlaboratory correlation - see also Rundberg and Smalley, 1989 on this). This uncertainty should be used as a guide for comparison of data from different laboratories - for example when comparing a result from an unknown sample to another laboratory's data set. The error bars on the individual points are ±2 standard errors (Std Error = Std Dev/$\sqrt{N-1}$) on the several analyses of the particular material used in calculation of the final result (and 2 standard errors average ±20). The standard error is a quantity which decreases with the greater number of analyses and is a measure of confidence in the mean value. It can be used to compare the result from the sample of unknown age to that of my standard material of known age. [To avoid confusion it should be added that the errors shown by the side of individual measurements in the result table in the appendix are ±2 standard deviations on the 200 or so results collected during the analysis of one filament (and this quantity is around ±20 for Sr results in static mode and ±12 for Sr results in dynamic mode). Given this precision it would probably be fairer to express all the $^{87}Sr/^{86}Sr$ results as 5 figures. They are, however, expressed by 6 figures because they are used in calculation of the Sr-derived dates and any rounding up of the figures before the calculation would lead to inaccuracy.]

In the first study, three samples were taken from each belemnite and analysed separately. Each was run once, or twice on the mass spectrometer (in static mode). After the mass spectrometer had been adjusted a further fourth sample was analysed and run (in dynamic mode). After normalising to the previous value of the standard (0.710230) this result had

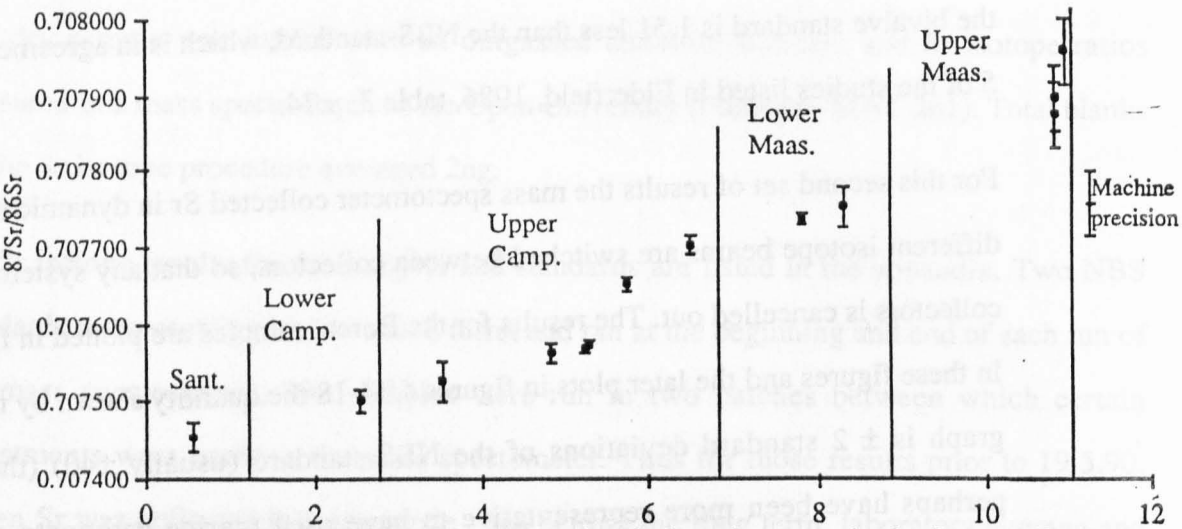


Figure 4/10. 87Sr/86Sr variation against belemnite zone (as in figure 2/8). Error bars show ±2 Std Errors on the average of 3 or 4 analyses for each point

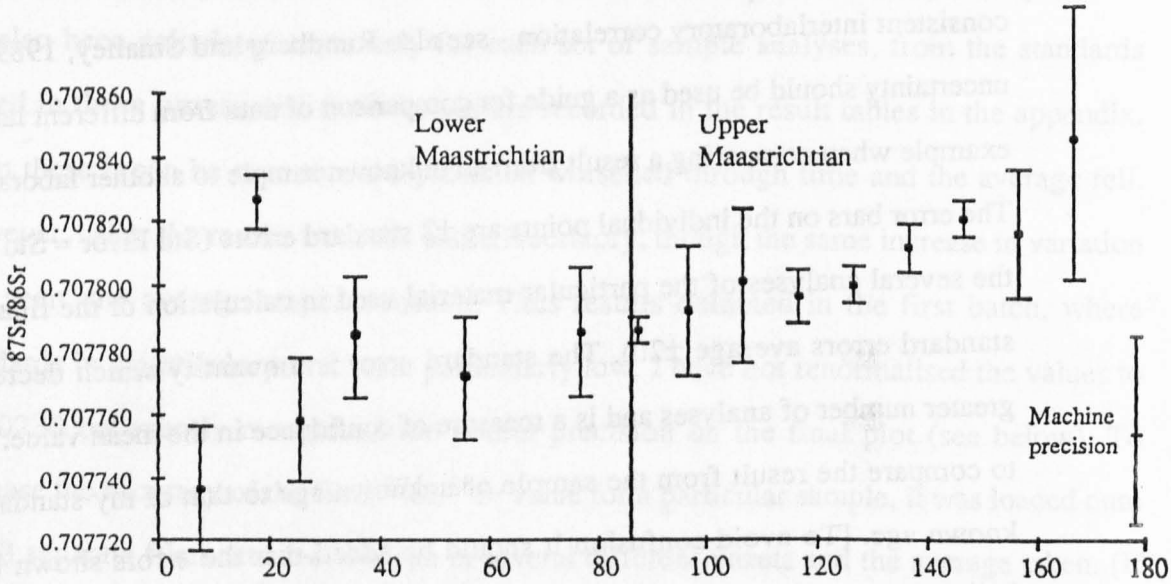


Figure 4/11. 87Sr/86Sr variation against stratigraphic height in metres for the Kronsmoor and Hemmoor sequences (as in figure 2/9). Error bars show ±2 Std Errors on the 3 separate runs for each sample.

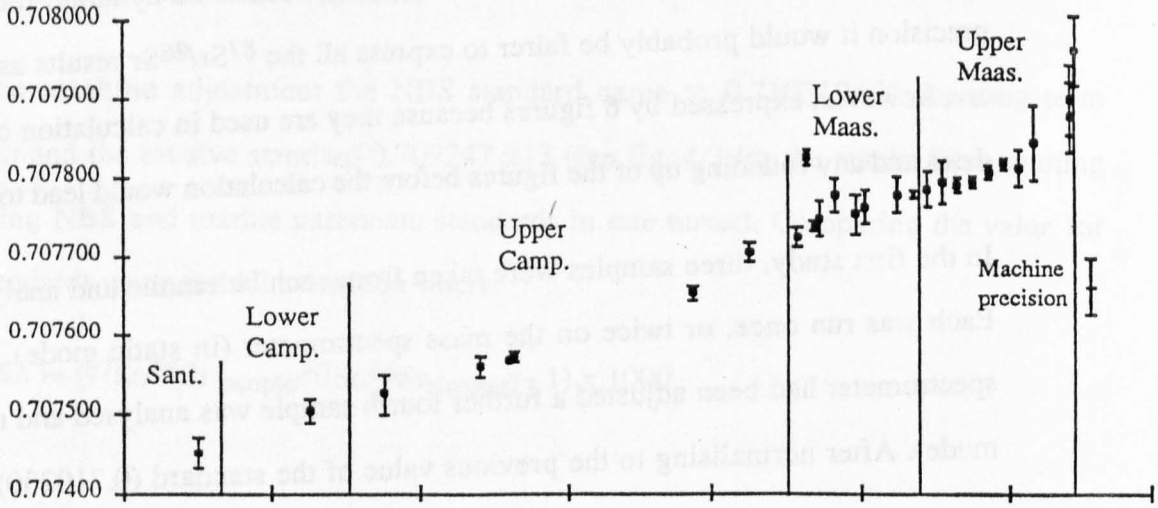


Figure 4/12. 87Sr/86Sr variation against time (see text). Error bars show ±2 Std Errors on the 3 separate runs for each sample.

almost no effect upon the average calculated from the three previous results. Moreover the separate samples from one belemnite produced results which showed no more variation from the mean than that due to the machine. From this and the high Sr-contents of the belemnites (see earlier under diagenesis) it became clear that diagenesis was not a relevant factor.

With this in mind, only one sample of each belemnite and of the pure carbonate sediment (which yielded a large amount of Sr after separation of the ions - another indication that it was not diagenetically altered) was analysed in the second study. Each sample was run three times with the mass spectrometer in dynamic mode and little variation in results was observed. All $^{87}Sr/^{86}Sr$ results for both studies are listed in the appendix.

4.3.4 Construction of the Sr-curve from the Boreal sequences

Figure 4/10 shows the $^{87}Sr/^{86}Sr$ results for the first set of samples. These are plotted against belemnite zone using Christensen's 1988 version of the belemnite zonation scheme, treating the relative thicknesses of the zones roughly as shown in that paper, and redrawn in figure 4/8. The plot produces two straight line portions offset in the *minor* zone, without intermediate points.

Figure 4/11 shows the $^{87}Sr/^{86}Sr$ results versus stratigraphic height for the Hemmoor/Kronsmoor samples. Unfortunately there is no independent evidence for the sedimentation rate to allow a plot against time. With the exception of the second point, which is offset, this approximates to a straight line. Using the same numbering as for the first graph, but readjusting the Maastrichtian belemnite zones according to their thicknesses at Kronsmoor and Hemmoor, the data sets are combined. A further adjustment has been to compensate for the apparent unconformity in the minor zone (which is admittedly somewhat speculative). In conclusion therefore, despite all the uncertainties in age assignment, the pattern of $^{87}Sr/^{86}Sr$ change through the latest Cretaceous approximates quite closely to a straight line (figure 4/12).

There were two belemnites which plotted significantly off this line. The first, belemnite no. 9 (listed in the appendix), apparently from the top of the *langei* zone at the top of the

Campanian, would have plotted below the general trend, but because there was some uncertainty as to the stratigraphic level from which it came and its weathered surface suggested some reworking, it has been omitted from figures 4/10 & 4/12. The second anomalous sample is the second of the Kronsmoor belemnites, and is included in figures 4/11 & 12, though it plots considerably above the general trend. The stratigraphic position is unequivocal and extensive reworking is not a viable explanation to explain the higher value. For reasons already given (high content of organically-bound Sr and narrow variation in results from different samples of the same specimen) I think that diagenetic introduction of this Sr by solution-reprecipitaion is unlikely given the lack of any cementation in the friable chalk sediment. It has not been established that belemnites do not incorporate low concentrations of Rb, for example bound to organic matter, though the concentration of Rb today in that belemnite was below the limit of detection by the ICP-MS (though in two others which plotted on the line Rb was detected).

This belemnite must therefore be recording the real value for the sea in which it formed. Belemnites were marine, nektonic animals and in North Germany they lived in a moderately shallow, epicontinental sea. Given that far more restricted Cretaceous environments did have waters with the marine $^{87}Sr/^{86}Sr$ signature (such as the lagoonal environment of Sierra de Montsech, see section 4.5.5), in general, the Boreal waters were almost certainly well mixed with respect to the other oceans (as seen on a time scale of years). Nevertheless, as only one small chip of the belemnite was measured, the value for the seawater ratio was in fact only sampled over only a few months. (For this reason, bulk sediment samples may be preferable as they may represent a time average over perhaps tens or even hundreds of years - as suggested by DePaolo, 1986). It is conceivable that the high $^{87}Sr/^{86}Sr$ value is a very short-lived local event. The occurrence of rare, anomalous blips emphasizes the potential fallibility of the method for dating single, isolated samples.

Using the data from figure 4/12, figure 4/13 tabulates the $^{87}Sr/^{86}Sr$ values for the stage boundaries and internal divisions (with average errors on these boundaries of the order of ±20). The highest $^{87}Sr/^{86}Sr$ values from Maastrichtian strata were from samples in the *casimirovensis* belemnite zone and *pulchellus pulchellus* brachiopod zone which gave

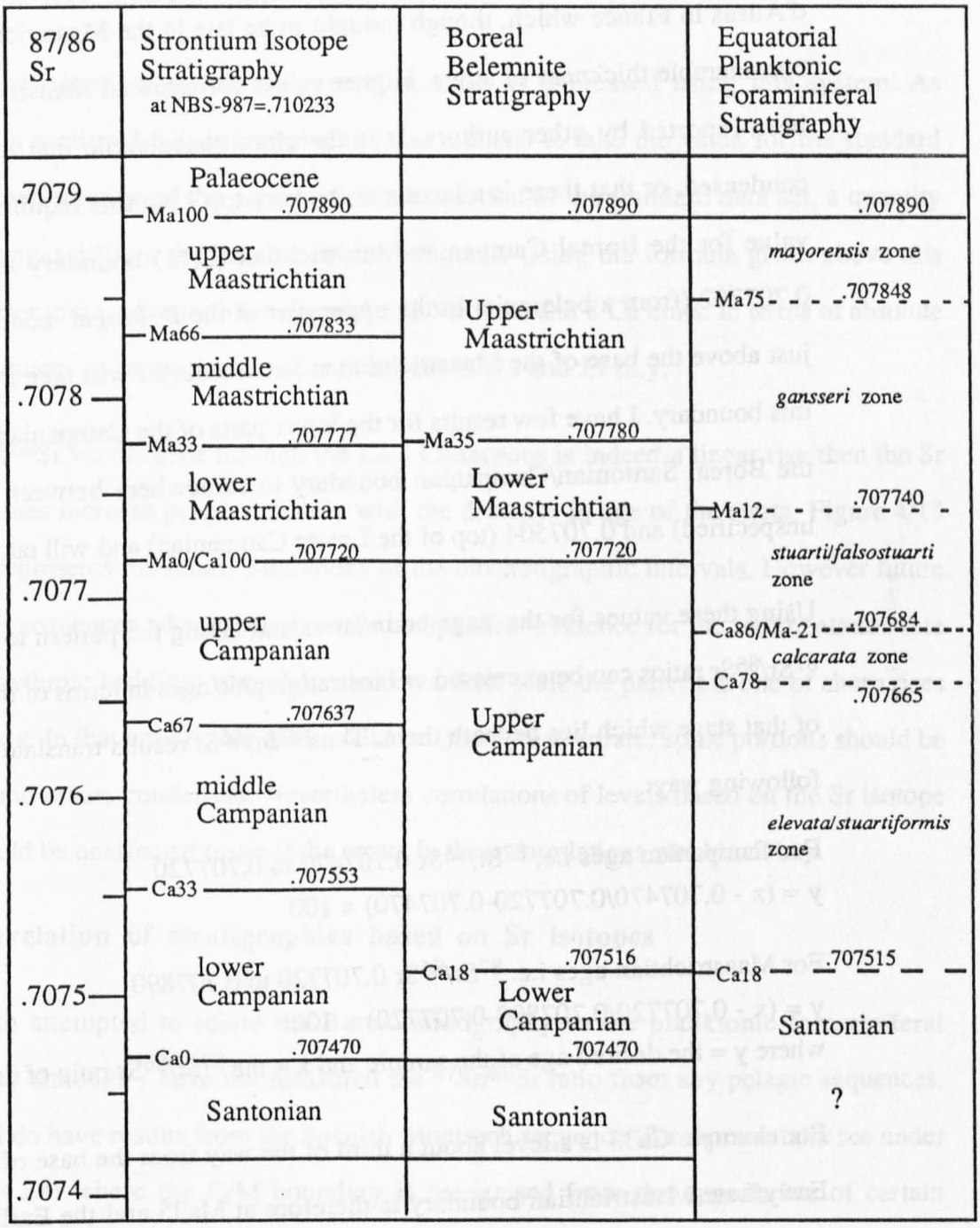


Figure 4/13. An attempt at correlation of the boreal belemnite, equatorial formainiferal and Sr isotope stratigraphies for the Santonian -Maastrichtian.

The Sr isotope dating of the planktonic foraminiferal stratigraphy is indirect and has used the following data: for the C/M boundary measurement of the 87Sr/86Sr ratio at the level of appearance of *O.macroporus* and *S. calcitrapoides*, in the Pyrenees & N. Italy - a level thought to be equivalent to the *G. calcarata* extinction level; the S/C boundary is very poorly defined using the Hess *et al.*, data; internal division of the Campanian and Maastrichtian uses the information on relative thicknesses of the planktonic foraminiferal zones from Van Hinte, 1976 and this information coincides with that of Signal, 1977 for the lengths of the *calcarata* and *mayorensis* zones.

values of 0.707875, but this is not well constrained. One sample from only a few metres below the fish clay at Stevns Klint frequently gave higher values nearer 0.707900. I have chosen a value of 0.707890 for the top of the Maastrichtian which is in line with that of the Hess *et al.* data. [However I found values of 0.707890 from rudist beds in the Marnes d'Auzas in France which, though thought to be late in the Maastrichtian are overlain by a considerable thickness of strata. Higher values for terminal Maastrichtian strata have also been reported by other authors. It is therefore conceivable that the Boreal sequence is condensed, or that there is a lacuna at the very top - but this requires further testing.] The value for the Boreal Campanian/Maastrichtian (C/M) boundary is somewhere between 0.707702 (from a belemnite in the upper part of the *B. langei* zone) and 0.707730 (from just above the base of the Maastrichtian at Kronsmoor). I will take a value of 0.707720 for this boundary. I have few results for the lower parts of the Campanian and have constrained the Boreal Santonian/Campanian boundary to somewhere between 0.707455 (Santonian unspecified) and 0.707504 (top of the Lower Campanian) and will take a value of 0.707470.

Using these values for the stage boundaries and taking the pattern to be a straight line, the $^{87}Sr/^{86}Sr$ ratios can be expressed as biostratigraphic ages in terms of the percentage of strata of that stage which lies beneath them. Thus $^{87}Sr/^{86}Sr$ results translate into these ages in the following way:

For Campanian ages i.e. $^{87}Sr/^{86}Sr$ 0.707470 to 0.707720
$y = (x - 0.707470/0.707720-0.707470) \times 100$

For Maastrichtian ages i.e. $^{87}Sr/^{86}Sr$ 0.707720 to 0.707890
$y = (x - 0.707720/0.707890-0.707720) \times 100$
where y = the desired age of the sample and x = the $^{87}Sr/^{86}Sr$ ratio of that sample

For example Ca33 is a level about a third of the way from the base of the Campanian. The Early/Late Maastrichtian boundary is therefore at Ma35 and the Early Maastrichtian thus accounts for only 1/3 of the total length of the stage (if the Sr isotope pattern is indeed linear). Even more disproportionate is the division between the Boreal Early and Late Campanian with the Early Campanian only 18% of the total. It should be stressed that the Campanian ages are based on a Boreal Campanian not a Tethyan Campanian, where the

stage is defined. However, the C/M boundary is defined from the base of the boreal Maastrichtian and so is in approximately the correct position and this division between Early and Late Campanian is that most commonly used. This method avoids all dubious correlations to radiometric tie points (although this can be done in the future by using these data when the correlations are more certain).

It is also necessary to assess the errors on dates as expressed using this system. As discussed in section 4.3.3, it is probably most realistic to take the value for the standard error as representative of the precision of construction of the standard data set, a quantity which averages ±20 on the last two of the 6 figures. Using the formula given above this gives an error to the Maastrichtian dates of ±12 Ma units and 8 Ca units. In terms of absolute ages this equates to an error somewhere between ±0.75 and ±1 m.y.

If the $^{87}Sr/^{86}Sr$ versus time through the Late Cretaceous is indeed a linear rise then the Sr isotope values increase proportionately with the decrease in age of the strata. Figure 4/13 therefore represents the relative durations of the biostratigraphic intervals. However future work using sequences where there is some independent evidence for the sedimentation rate (such as rhythmic bedding) may show that on a finer scale the pattern is one of sharp rises and plateaux. In that case figure 4/13 would be slightly inaccurate; some portions should be stretched and others condensed. Nevertheless correlations of levels based on the Sr isotope values would be unaffected (even if the errors in these correlations would not be).

4.3.5 Correlation of stratigraphies based on Sr isotopes

I have also attempted to relate the Boreal stratigraphy to the planktonic foraminiferal stratigraphy although I have not measured the $^{87}Sr/^{86}Sr$ ratio from any pelagic sequences. However I do have results from the Spanish Montsech sequence (for more details see under section 4.4.2d) where the C/M boundary is recognised from the appearance of certain orbitoids which elsewhere in the Pyrenees coincide with the *calcarata* extinction level. These suggest a planktonic foraminiferal boundary at around 0.707680 (at NBS-987=0.710230). The appearance of these orbitoids at M. Jouf, N. Italy is at a well-defined level of 0.707684. Both these two estimates are essentially identical to the value found by linear regression

through the (normalised) data of Hess *et al.* which also produces an answer of 0.707684. The correlation of the *calcarata* extinction level with the *B. langei* zone is supported by the biostratigraphic evidence which is discussed in section 5.0. Using the Sr-derived dating system, the planktonic foraminiferal boundary is at a level in the Campanian about 14% of the way from the top i.e. Ca86.

After establishing the planktonic foraminiferal C/M boundary by those means I have then indicated the position of the *mayorensis* and *calcarata* zones using their lengths relative to that of the stage as defined by both Van Hinte (1976) and Signal (1977). Division of the remaining portion of the Maastrichtian is highly uncertain as it varies so much between different authors. There may be worse offsets in the Santonian/Campanian boundaries although I have too little data on this to make worthwhile comments.

4.4 Dating of rudist bivalves using Sr isotope stratigraphy

4.4.1 Selection of material, diagenetic screening, sample preparation and measurement of $^{87}Sr/^{86}Sr$ on mass spectrometer

Most of this work has not been to establish the values for the standard curve, but dating samples of unknown age. Material has frequently been in an imperfect diagenetic state and of limited quantity. Had I used the techniques adopted by Popp *et al.* nearly all this material would have been excluded. Instead, given the available hand specimens, I have used a range of different types of material from those least likely, to those most likely, to have been affected by diagenesis, in order to understand some of the diagenetic trends of the system. I considered the best material to be organic-rich calcite, such as the outer layer of requieniid rudists. The thick compact prismatic calcite of the right valve of hippuritid rudists (in some cases also quite organic rich), or the left valve of radiolitids were also thought reliable. In section the calcite showed various degrees of neomorphism and the extent of this was recorded (see tables in appendix).

In some sediments the only macrofossils available were the right valves of radiolitids. This calcite includes areas of shell filled by cement ("cellular calcite"). In several examples these

could be seen to be fringing cements, which must have been early marine in origin. This is in agreement with what has generally been assumed by other workers. The calcite would then be quite useable because the cements would have the same $^{87}Sr/^{86}Sr$ ratio as the shell. Indeed the samples might even be better than the compact calcite samples because the interlocking framework of laminae walls and cement-filled cavities could potentially be more diagenetically resistant than the original compact prismatic texture. However, another problem arises with the use of radiolitid cellular calcite, that of the entrapment of sediment between the growth laminae and in the cells and care should have been taken to avoid contamination (a problem not initially envisaged!). Other material such as bulk sediment, portions of the aragonitic inner layer of rudists now recrystallised to calcite, and some other cements were also included. The recrystallised aragonite was included to monitor the $^{87}Sr/^{86}Sr$ ratio in pore fluids at the time the aragonite recrystallised (conventionlly described as late in early diagenesis). The cements and the bulk sediment helped to monitor the pore water ratio later in diagenesis.

Techniques of sample dissolution and ion separation were as discussed for the Boreal samples in section 4.3.1.

4.4.2 $^{87}Sr/^{86}Sr$ Results

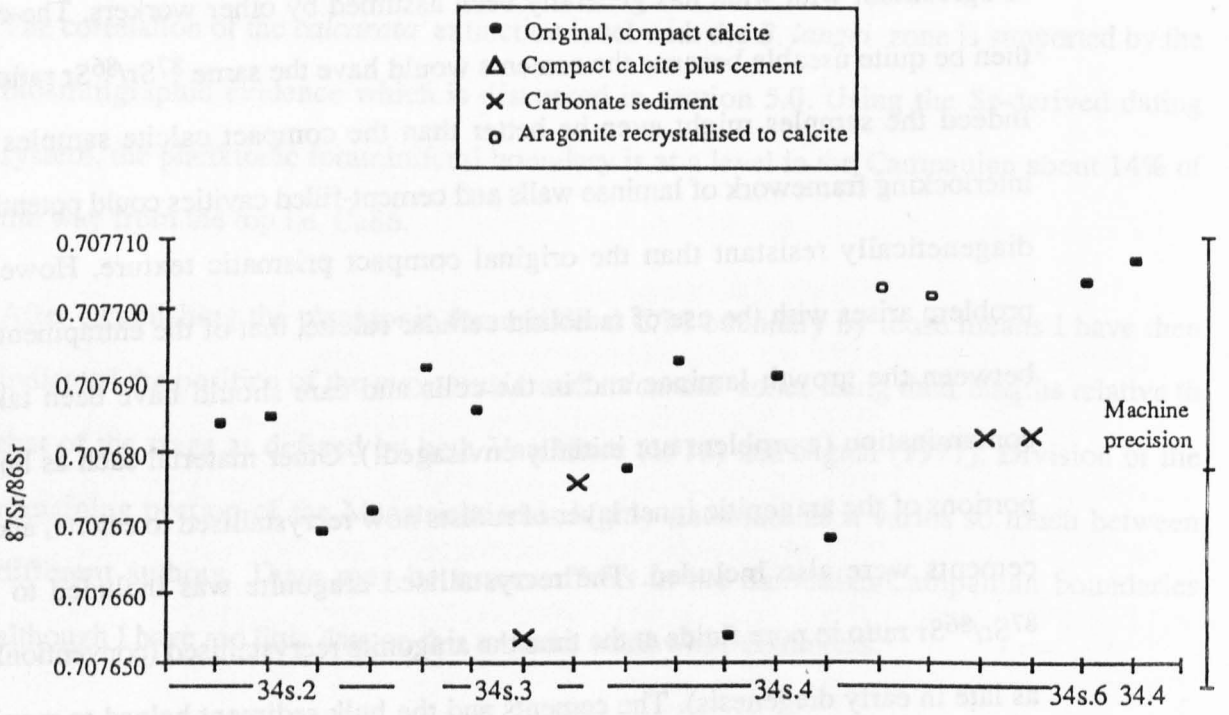
For most localities the average result is calculated only from the data points made with compact calcite samples. In some cases only cellular calcite was used, usually because nothing else was available. For a result from one stratigraphic level to be reliable, the variation, or standard deviation, of results must be the same as that of the standard.

The Sr-derived dates are not given numerical errors because they are only actually used in combination with other information about the ages of beds above and below those in the sequence.

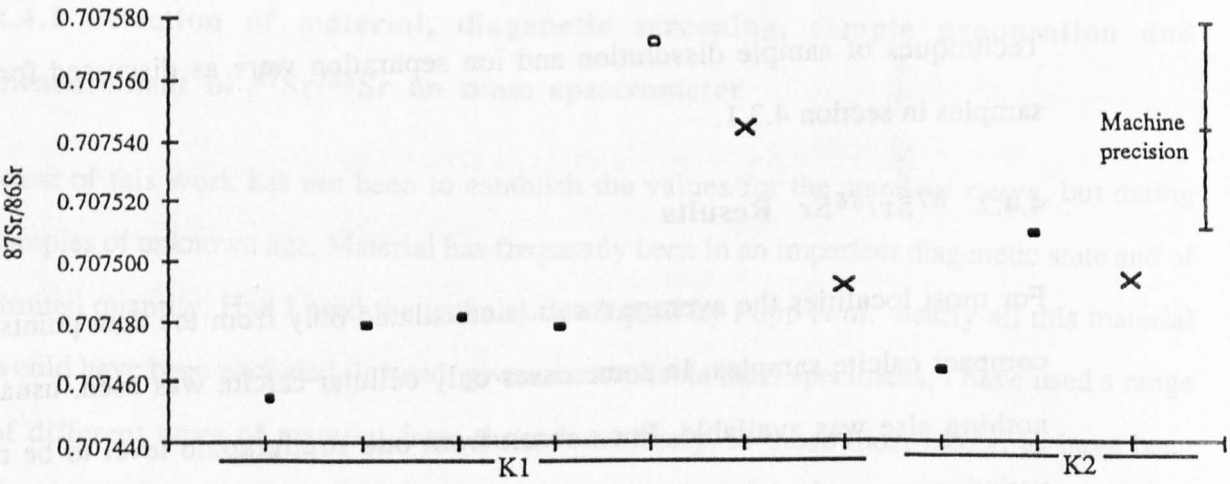
4.4.2a M.Jouf, N.Italy

I collected the samples from M. Jouf during sedimentary logging of the sequence, details of which can be found in Swinburne & Noacco (in press), a copy of which is available in the

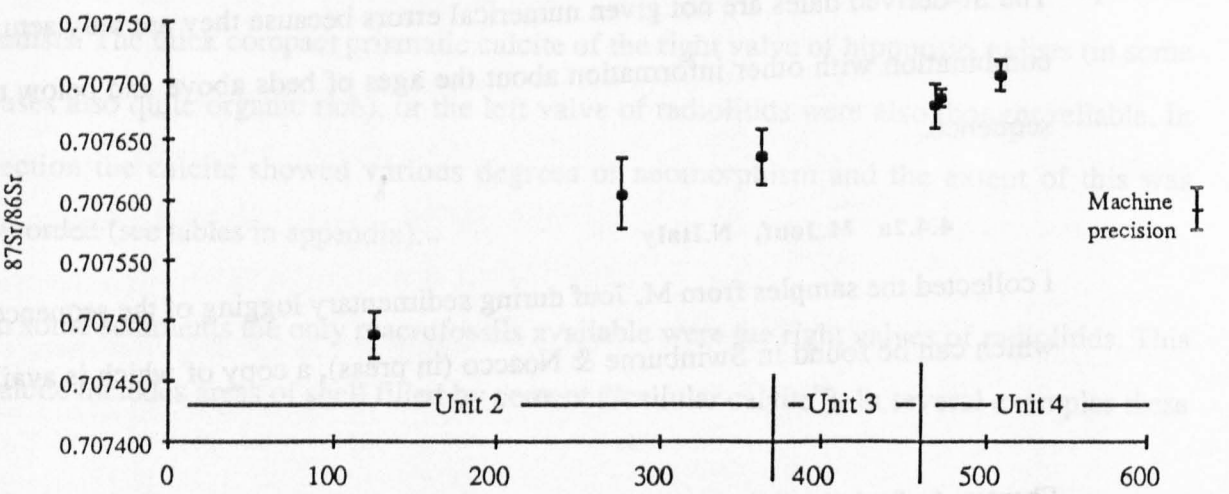
Figure 4/14. 87Sr/86Sr results for M. Jouf, N. Italy



i) Variation in 87Sr/86Sr for different sample materials from 471m

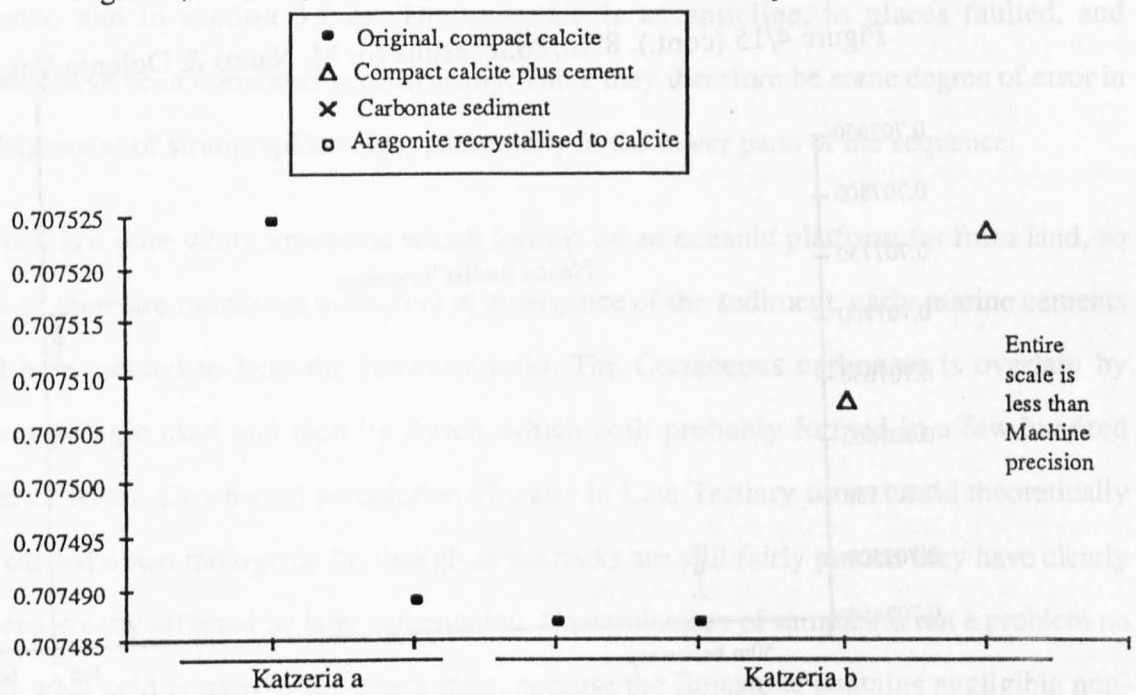


ii) Variation in 87Sr/86Sr for different sample materials from 124m

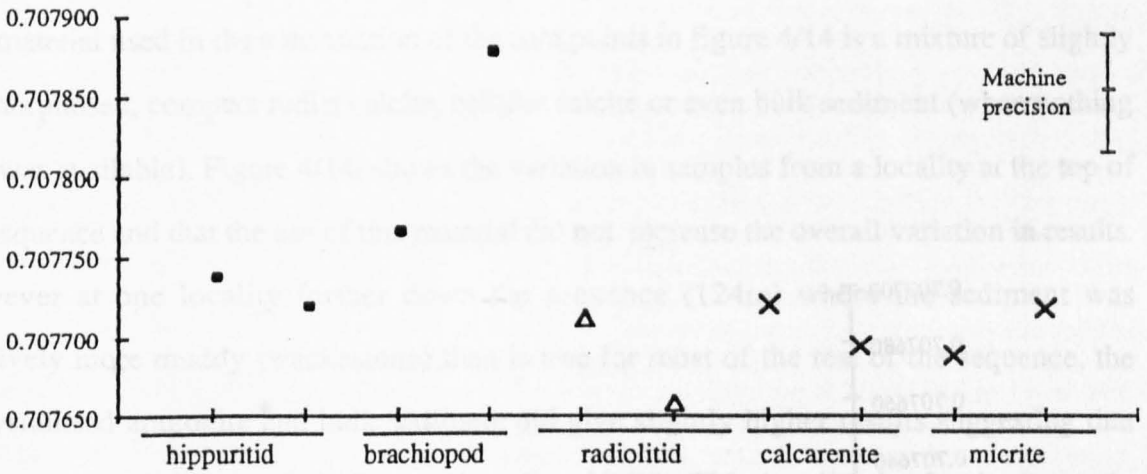


iii) Average of results for each stratigraphic height. Error bars show ±2 Std Errors on the 3 separate runs for each sample.

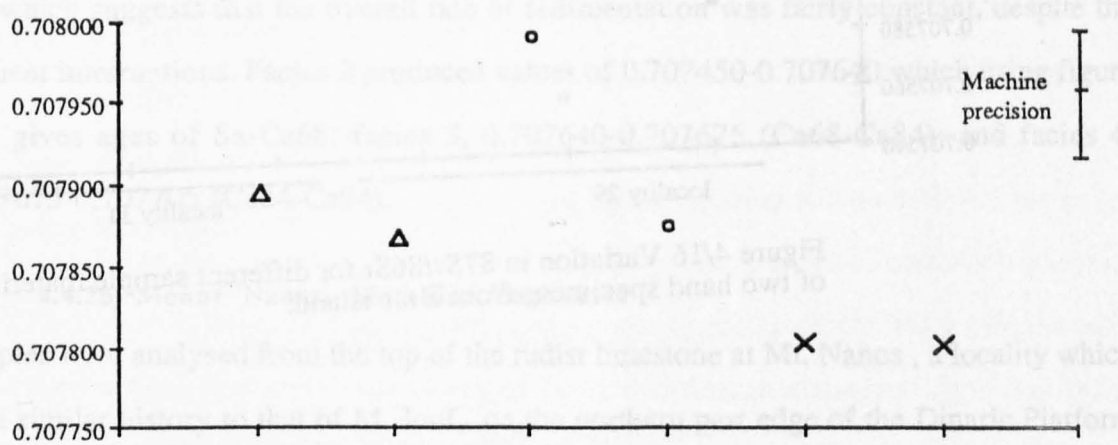
Figure 4/15. 87Sr/86Sr results for M. Nanos & Dolenja Vas, S. Slovenia



i) Variation in 87Sr/86Sr for different sample materials from locality 20.4, M. Nanos.

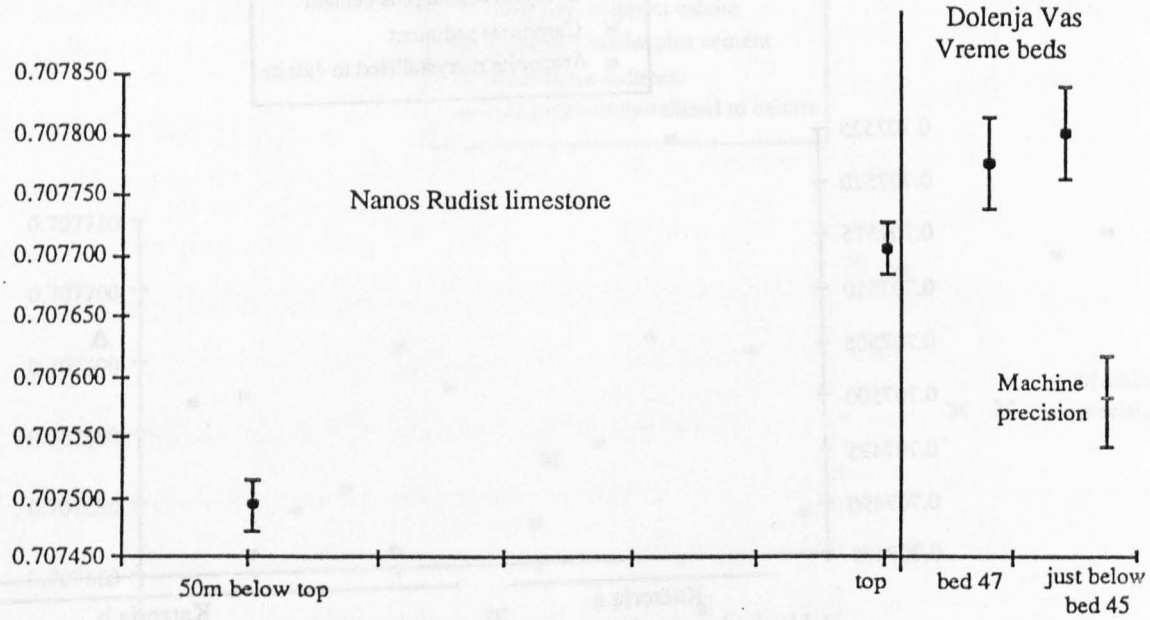


ii) Variation in 87Sr/86Sr for different sample materials from locality 20.2, M. Nanos



iii) Variation in 87Sr/86Sr for different sample materials from locality 32.1, Dolenja Vas

Figure 4/15 (cont.). 87Sr/86Sr results for M. Nanos & Dolenja Vas, S. Slovenia



iv) Average of results for each stratigraphic height. Error bars on M. Nanos points show ±2 Std Errors on the several analyses. Error bars on Dolenja Vas points show machine precision.

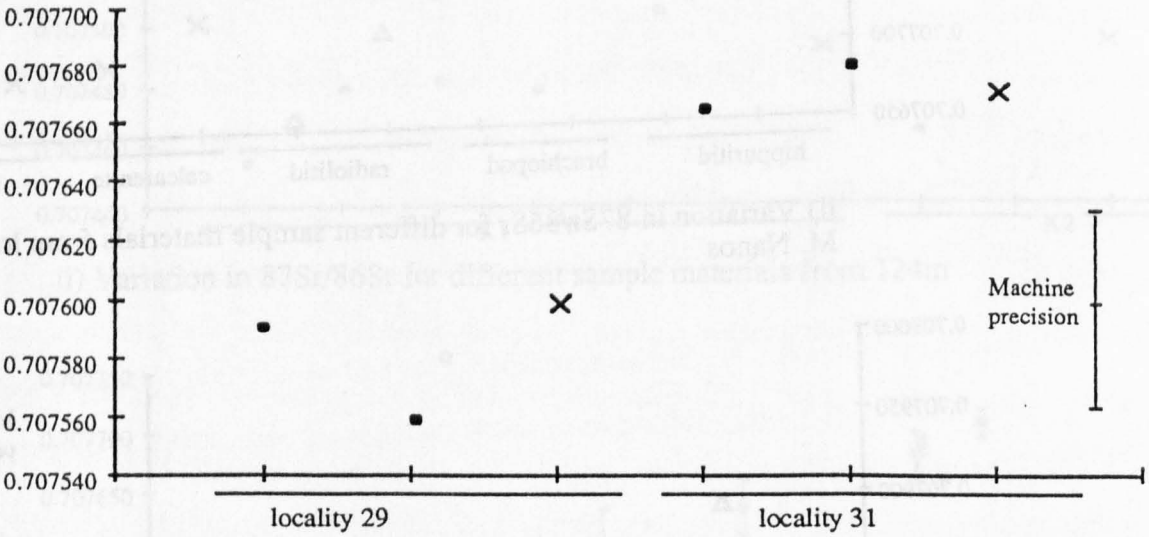


Figure 4/16 Variation in 87Sr/86Sr for different sample materials of two hand specimens from Brac island.

appendix, and in section 3.2.2a. The mountain is an anticline, in places faulted, and localities have been correlated geometrically. There may therefore be some degree of error in the assignment of stratigraphic height particularly in the lower parts of the sequence.

The rock is a pure white limestone which formed on an oceanic platform far from land, so although there are numerous indicators of emergence of the sediment, early marine cements could be expected to bear the seawater ratio. The Cretaceous carbonate is overlain by Tertiary pelagic marl and then by flysch, which both probably formed in a few hundred metres of water. Downward percolation of water in Late Tertiary times could theoretically have carried down radiogenic Sr, though as the rocks are still fairly porous they have clearly not been greatly affected by later cementation. Contamination of samples is not a problem no matter what acid is used in the dissolution, because the limestone contains negligible non-carbonate material.

The material used in the construction of the data points in figure 4/14 is a mixture of slightly neomorphosed, compact rudist calcite, cellular calcite or even bulk sediment (when nothing else was available). Figure 4/14i shows the variation in samples from a locality at the top of the sequence and that the use of this material did not increase the overall variation in results. However at one locality further down the sequence (124m) where the sediment was relatively more muddy (wackestone) than is true for most of the rest of the sequence, the recrystallised aragonite and bulk sediment did give slightly higher results suggesting that there was some diagenetic influence (see fig. 4/14ii). This locality is also both poorly constrained in terms of stratigraphic height. However in general, the graph shows a straight line which suggests that the overall rate of sedimentation was fairly constant, despite the frequent interruptions. Facies 2 produced values of 0.707450-0.707640 which using figure 4/13 gives ages of Sa-Ca68; facies 3, 0.707640-0.707675 (Ca68-Ca84); and facies 4, 0.707675-0.707705 (Ca84-Ca94).

4.4.2b Mount Nanos, Slovenia, Yugoslavia

Samples were analysed from the top of the rudist limestone at Mt. Nanos , a locality which has a similar history to that of M. Jouf, on the northern part edge of the Dinaric Platform

and the nearby locality of Dolenja Vas in the shallower water of an intrashelf basin (see section 3.2.1a).

At the lower locality on M.Nanos, around 50m from the top, a specimen of *Katzeria* was analysed for $^{87}Sr/^{86}Sr$. The results (fig. 4/15i) for calcite and recrystallised aragonite are all very close to each other and the average, of 0.707497 (Ca11) could probably be taken of all the samples, though only the compact calcite points have been used. Results from the top of the rudist limestone (fig. 4/15ii) show a fairly wide variation with calcite of the brachiopod sample giving anomalously high values compared with a compact calcite from a hippuritid, from the bulk sediment and, surprisingly, a geopetal cement from the cavity in the brachiopod. Results from the bulk sediment (a micrite) at the locality immediately above this were similar to the latter. The brachiopod results are excluded from the final average which is made with the others and comes to 0.707707 (Ca95).

At Dolenja Vas the Cretaceous strata known as the Vreme beds, which overlie the M.Nanos and M.Jouf rudist limestone, were dated. At a level inside the Vreme beds (bed 47 of Drobne *et al.*, 1987) only bulk sediment which was a bituminous, foraminiferal limestone was available. Two analysed samples gave gave very similar results, averaging 0.707778 (Ma34). Material available from the top of the Vreme beds (just below bed 45) was cellular calcite, recrystallised aragonite and the bulk sediment, which was also a bituminous limestone but with a high proportion of requieniid debris (and therefore probably quite reliable). Results are highly variable (fig. 4/15iii), probably mainly due to machine malfunction (all results for that period were highly variable). Results from the sediment suggest 0.707803 (Ma49) and the first results from the cellular material were similar but later re-runs of these were much higher. The recrystallised aragonite also gave much higher results. The results from the Vreme beds can therefore not be considered conclusive. Yet considering that the unit is only about 12m thick, it probably does not represent a substantial time period and I favour an answer of Ma49 for the upper horizon. A compilation of the Nanos and Dolenja Vas results are presented in figure 4/15iv.

4.4.2c Brač island, Hercegovina, Yugoslavia

Only two specimens were analysed and these were both from the Brač marble, one from eastern Brač and the other from northern Brač (see section 3.2.2b). Compact calcite and bulk sediment were analysed from both. The two specimens gave significantly different answers - 0.707497 (Ca11) for the former and 0.707591 (Ca48) for the latter (fig. 4/16). If the difference is diagenetic I would favour the lower one. More likely however, is that the formation is of different ages in different parts of the island.

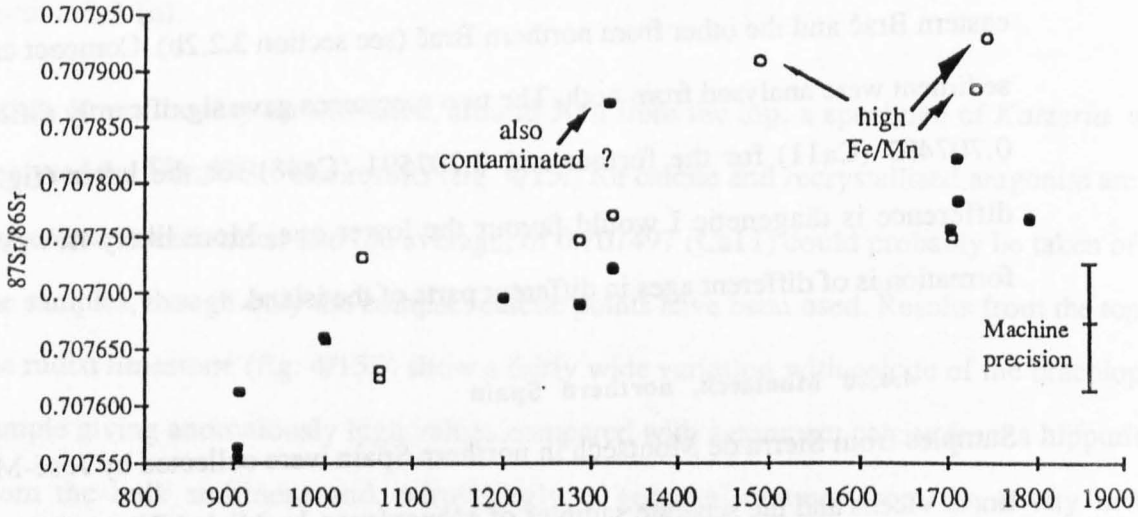
4.4.2d Montsech, northern Spain

Samples from Sierra de Montsech in northern Spain were collected by José-Maria Pons and Enric Vicens and the separate samples of *Monopleura* by Michel Bilotte. The stratigraphy of the sequence below 1700m is straightforward and localities above 1700m, in the Tremp Formation are reliably correlated to the main sequence (see section 3.1.1aii).

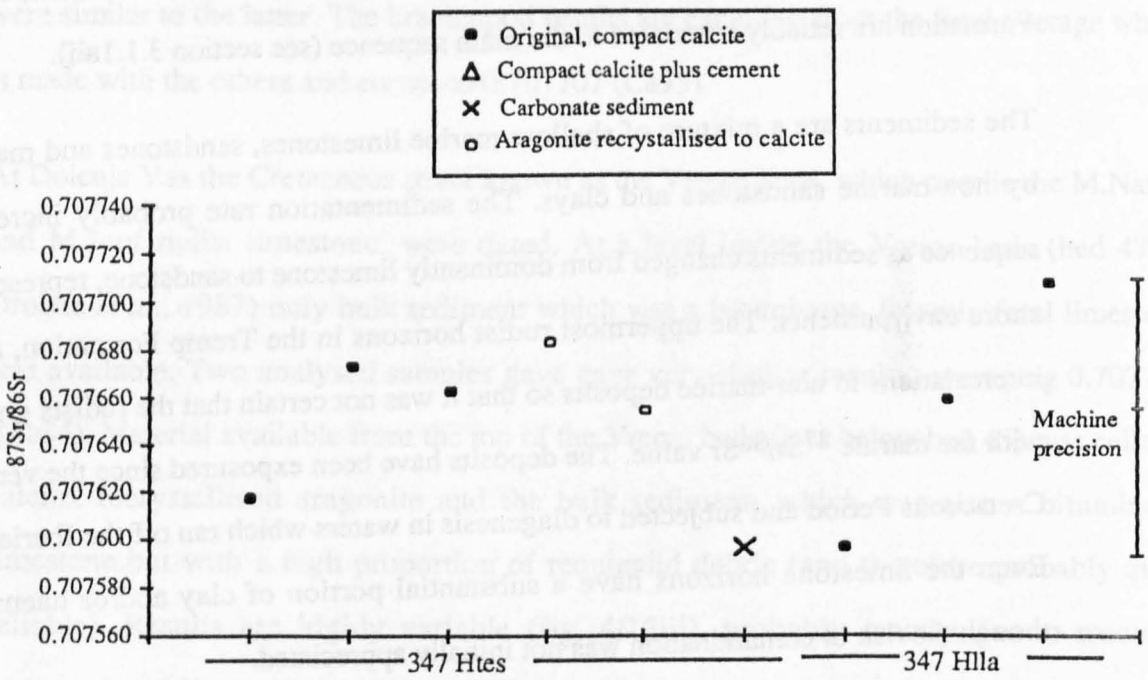
The sediments are a mixture of shallow marine limestones, sandstones and marls, overlain by non-marine sandstones and clays. The sedimentation rate probably increased up the sequence as sediments changed from dominantly limestone to sandstone, representing nearer shore environments. The uppermost rudist horizons in the Tremp Formation, are lagoonal intercalations in non-marine deposits so that it was not certain that the rudists grew in waters with the marine $^{87}Sr/^{86}Sr$ value. The deposits have been exposured since the very end of the Cretaceous Period and subjected to diagenesis in waters which ran off the Iberian continent. Even the limestone horizons have a substantial portion of clay and/or haematitic sand, though the risk of contamination was not initially appreciated.

In the first study, chips of compact and cellular calcite were dissolved in 2.5*N* HCl and another, adjacent sample weighed and similarly dissolved for measurement of the trace element concentration. The first set of results shown in figure 4/17i showed several anomalously high points, 3 out of 4 of which were from cellular calcite from the top of the sequence. These also showed anomalously high Fe and Mn contents (Fe>1000ppm, Mn>100ppm) in the adjacent chip of calcite and were excluded from the data set on the basis of contamination (diagenesis being thought less likely though also possible). The fourth point, from a compact sample plotted well above the points from two other rudists form the

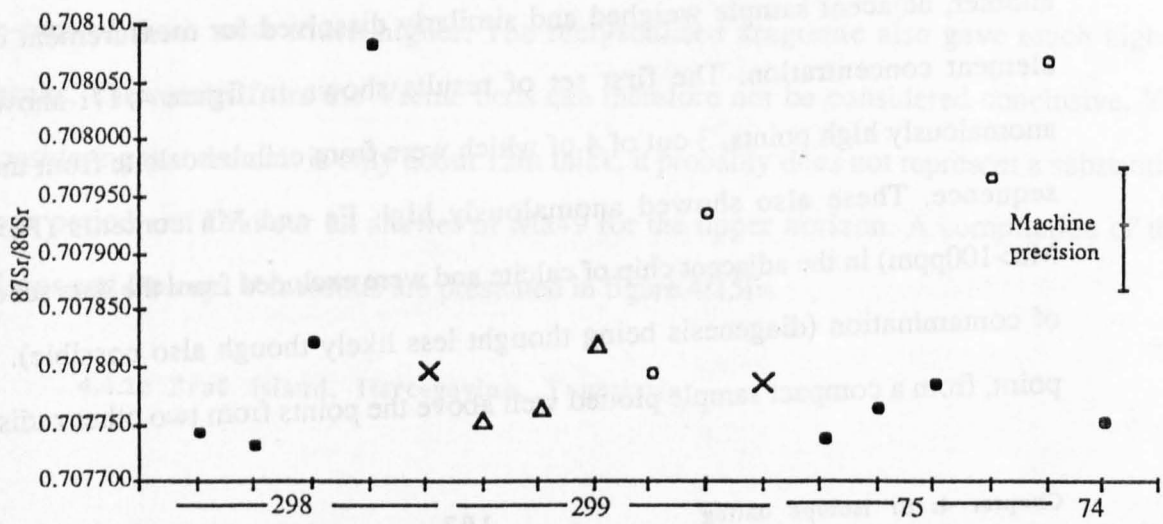
Figure 4/17. 87Sr/86Sr results for Montsech



i) Variation in 87Sr/86Sr for the first set of results from Montsech showing the effects of contamination.

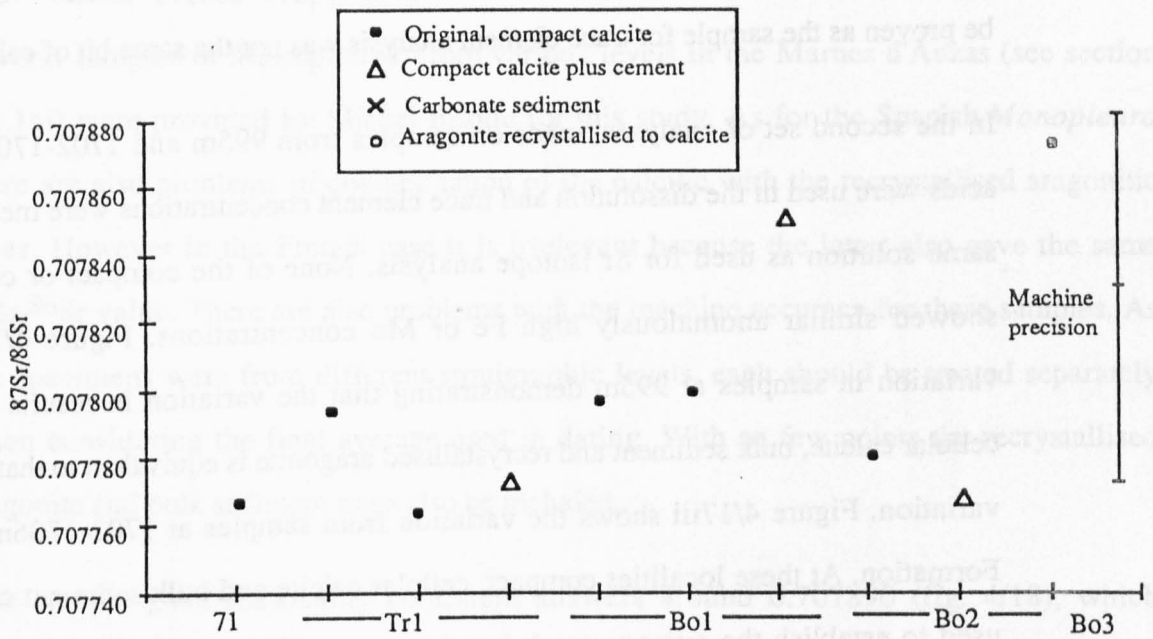


ii) Variation in 87Sr/86Sr for different sample materials from 995m

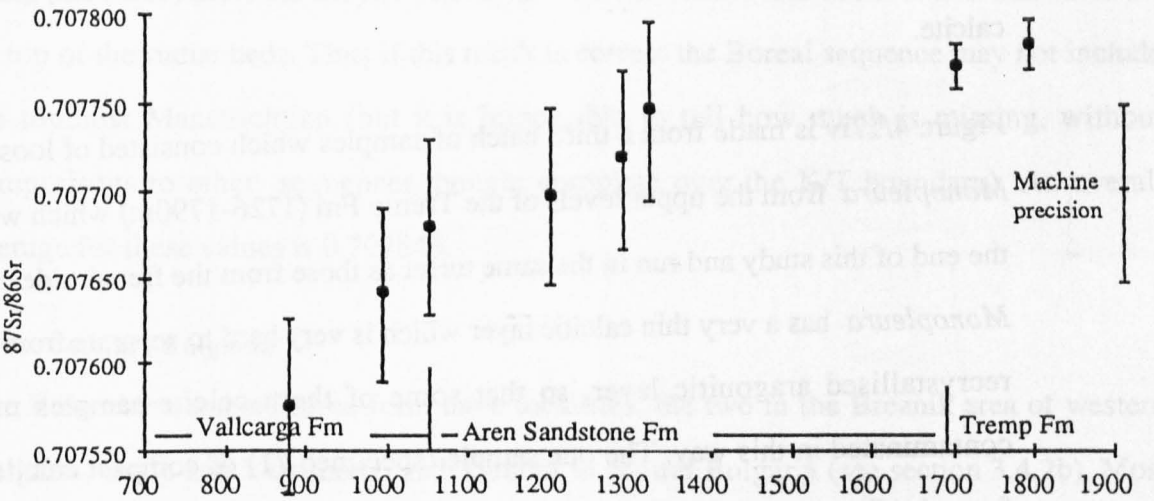


iii) Variation in 87Sr/86Sr for different sample materials from 1702-1706m

Figure 4/17 (cont.). 87Sr/86Sr results for Montsech



iv) Variation in 87Sr/86Sr for different sample materials from 1726-1790m



v) Average of results for each stratigraphic height. Error bars on points in Tremp Fm show ±2 Std Errors on the several analyses. Error bars on other points show machine precision

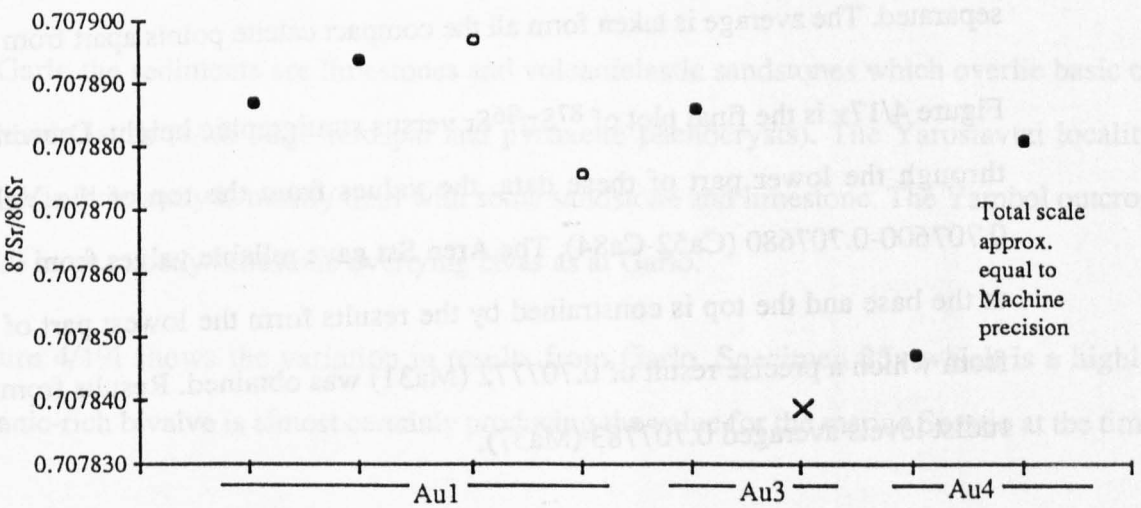


Figure 4/18. Variation in 87Sr/86Sr for different sample materials from samples of *Monopleura* from the Marnes d'Auzas.

same stratigraphic level and was thought to be similarly contaminated (though this could not be proven as the sample for trace element analysis was not the same bit of calcite).

In the second set of analyses, made on samples from 995m and 1702-1709m, only weak acids were used in the dissolution and trace element concentrations were measured from the same solution as used for Sr isotope analysis. None of the compact or cellular samples showed similar anomalously high Fe or Mn concentrations. Figure 4/17ii shows the variation in samples at 995m demonstrating that the variation in results from compact, cellular calcite, bulk sediment and recrystallised aragonite is equivalent to that of the machine variation. Figure 4/17iii shows the variation from samples at 1702-1706m in the Tremp Formation. At these localities compact, cellular calcite and bulk sediment could have been used to establish the average result but the recrystallised aragonite plotted much higher, carrying a radiogenic signature. In fact the average has been taken of the 7 points of compact calcite.

Figure 4/17iv is made from a third batch of samples which consisted of loose specimens of *Monopleura* from the upper levels of the Tremp Fm (1726-1790m) which were analysed at the end of this study and run in the same turret as those from the french side of the Pyrenees. *Monopleura* has a very thin calcitic layer which is very hard to separate from portions of the recrystallised aragonitic layer, so that some of these calcite samples may have been contaminated in this way. The one sample (specimen 71) of compact calcite from 1790m, from the first study is also included in this plot. Again the recrystallised aragonite can plot much higher as can some calcite samples (such as Bo3) which have been incompletely separated. The average is taken form all the compact calcite points apart from Bo3.

Figure 4/17v is the final plot of $^{87}Sr/^{86}Sr$ versus stratigraphic height. Drawing a best fit line through the lower part of these data, the values from the top of the Vallcarga Fm are 0.707600-0.707680 (Ca52-Ca84). The Aren Sst gave reliable values from 0.707680 (Ca84) at the base and the top is constrained by the results form the lowest part of the Tremp Fm from which a precise result of 0.707772 (Ma31) was obtained. Results from the uppermost rudist levels averaged 0.707783 (Ma37).

4.4.2e French Prepyrenees

Several samples of *Monopleura* from various levels in the Marnes d'Auzas (see section 3.1.1ai) were provided by Michel Bilotte for this study. As for the Spanish *Monopleura* there are also problems of contamination of the calcitic with the recrystallised aragonitic layer. However in the French case it is irrelevant because the latter also gave the same $^{87}Sr/^{86}Sr$ value. There are also problems with the machine accuracy for these samples. As the specimens were from different stratigraphic levels, each should be treated separately when considering the final average used in dating. With so few points the recrystallised aragonite and bulk sediment must also be included.

One sample gave reasonably consistent answers around 0.707890 (fig. 4/18), which indicates a value near to the Boreal K/T boundary, though according to Bilotte (Bilotte, 1985, p264-266) there are around 80m of Cretaceous marine and 100m of non-marine strata on top of the rudist beds. Thus if this result is correct the Boreal sequence may not include the topmost Maastrichtian (but it is impossible to tell how much is missing, without comparisons to other sequences thought complete over the K/T boundary). An overall average for these values is 0.707846.

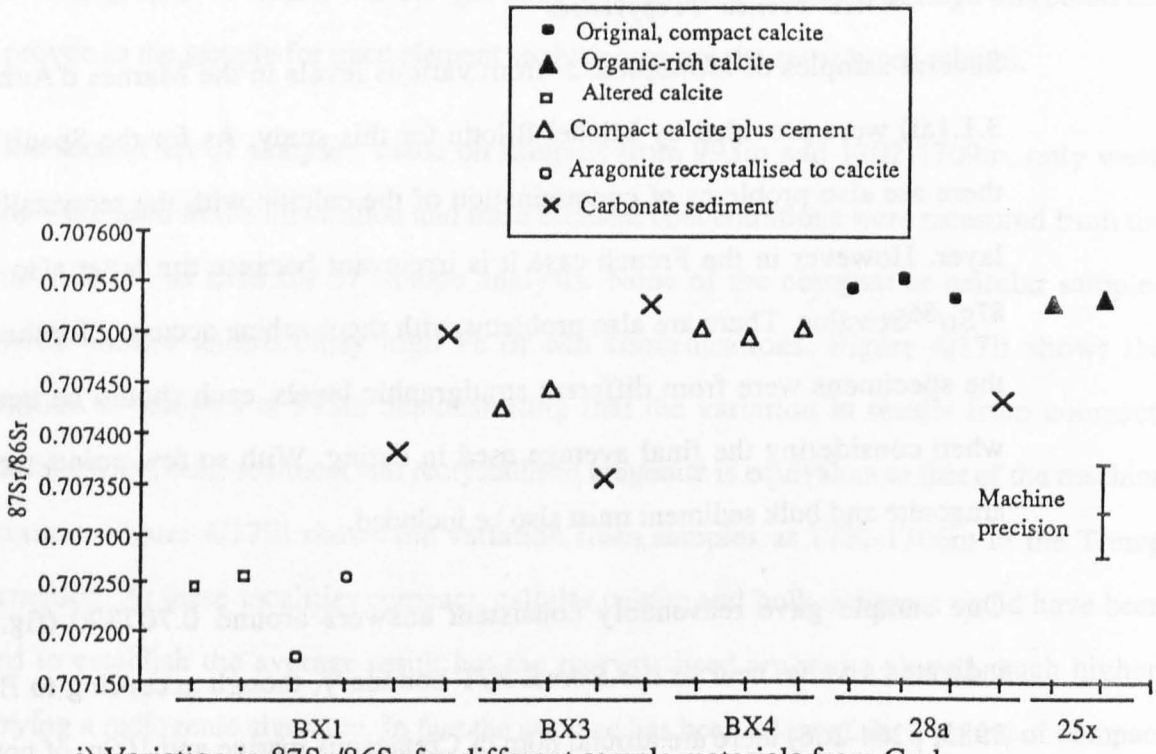
4.4.2f Bulgaria

The Bulgarian samples come form three localities, the two in the Breznik area of western Bulgaria, Garlo and Yaroslavtzi and Yambol in central Bulgaria (see section 3.4.2b). Most of the material I collected myself, though some of the Garlo material, specimens BX1, X3 & X4 were sent to be by Angel Pamouktchiev and come from a mixture of stratigraphic levels.

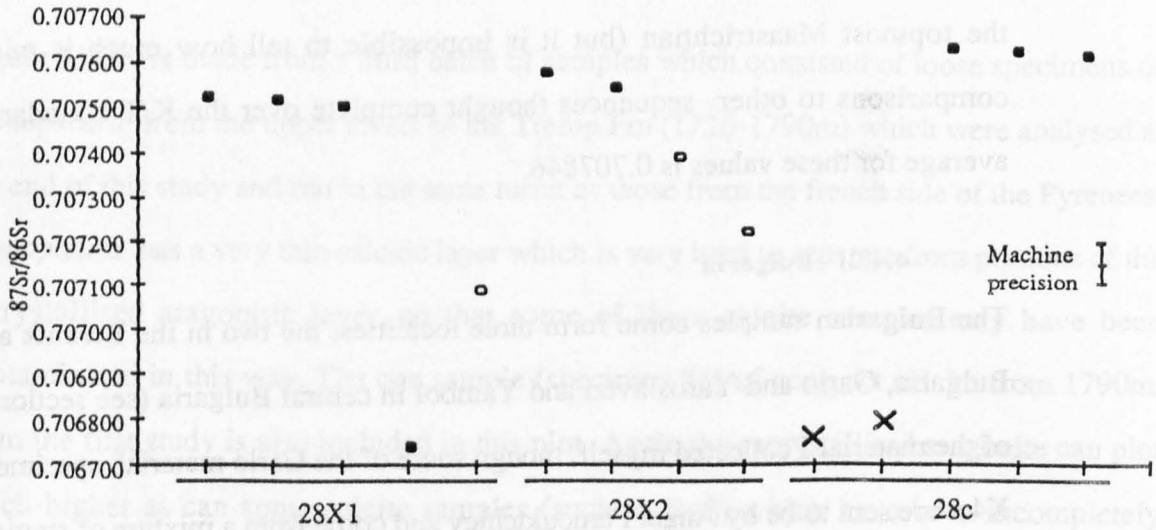
At Garlo the sediments are limestones and volcaniclastic sandstones which overlie basic or andesitic lavas (with large feldspar and pyroxene phenocrysts). The Yaroslavtzi locality which is 3km away is mostly marl with some sandstone and limestone. The Yambol outcrop is not large, mostly limestone overlying lavas as at Garlo.

Figure 4/19i shows the variation in results from Garlo. Specimen 25x which is a highly organic-rich bivalve is almost certainly producing the value for the marine Sr ratio at the time

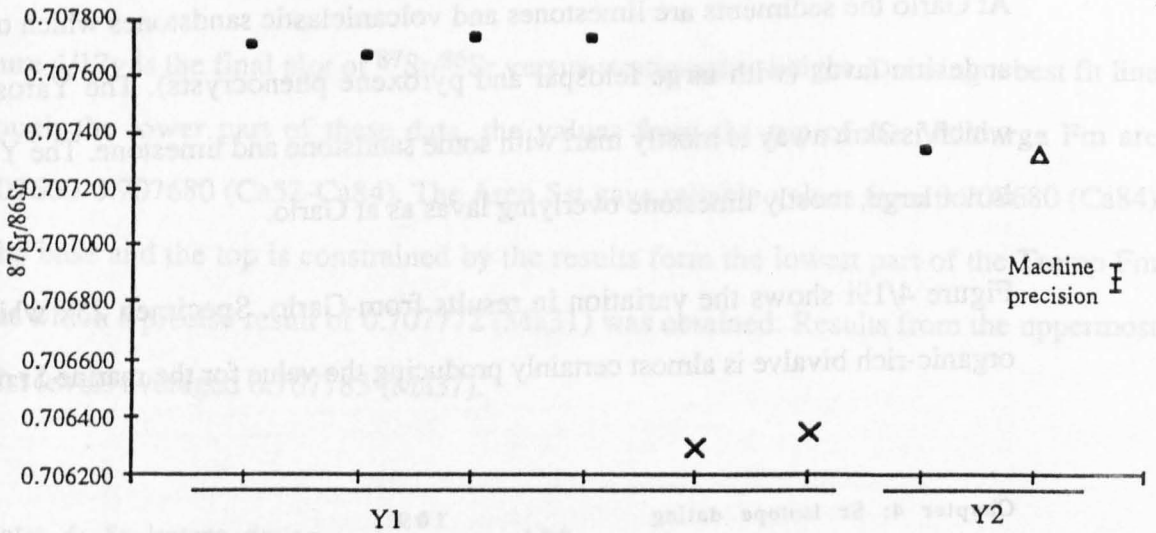
Figure 4/19. 87Sr/86Sr results for Bulgaria.



i) Variation in 87Sr/86Sr for different sample materials from Garlo

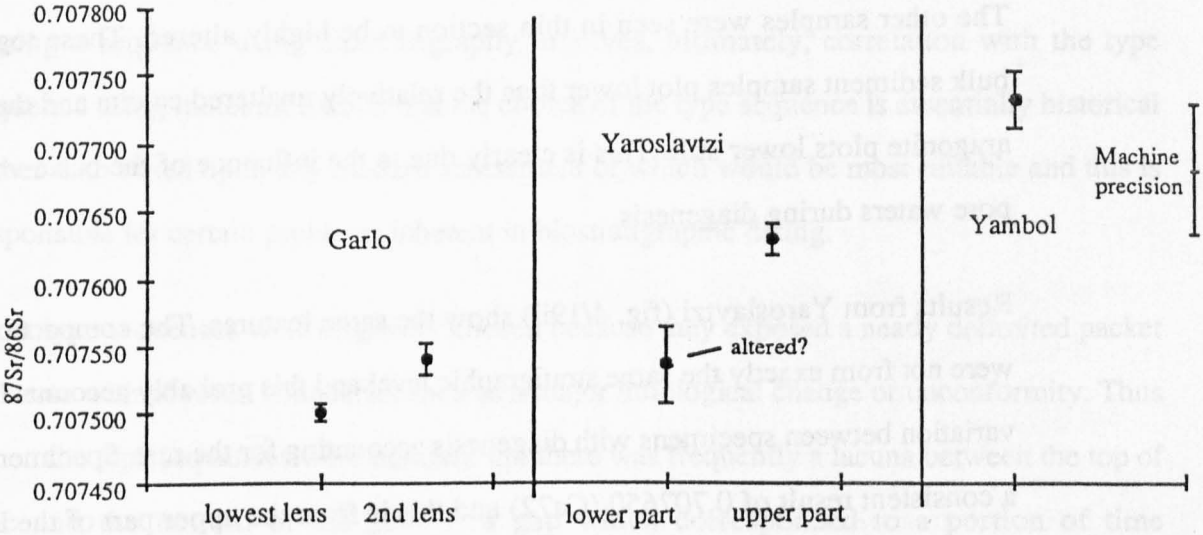


ii) Variation in 87Sr/86Sr for different sample materials from Yaroslavtzi



iii) Variation in 87Sr/86Sr for different sample materials from Yambol

Figure 4/19. (cont.)



iv) Average of results for each stratigraphic height. Error bars show ±2 Std Errors on the several analyses.

of formation of the carbonate (see earlier under section 4.2.2). 28a, also compact calcite gives the same answer, 0.707550 (Ca32). BX4 is well preserved cellular calcite and plots slightly below these at 0.707500 (Ca12). It is quite likely that this too is giving a genuine marine $^{87}Sr/^{86}Sr$ signature and that this sample is from a slightly lower stratigraphic level. The other samples were seen in thin section to be highly altered. These together with the bulk sediment samples plot lower than the relatively unaltered calcite and the recrystallised aragonite plots lower still. This is clearly due to the influence of the basic volcanics on the pore waters during diagenesis.

Results from Yaroslavtzi (fig. 4/19ii) show the same features. The compact calcite samples were not from exactly the same stratigraphic level and this probably accounts for some of the variation between specimens with diagenesis accounting for the rest. Specimen 28c produces a consistent result of 0.707650 (Ca72) and this is from the upper part of the locality from a higher level that 28X1 & X2. These specimens give substantially lower answers than 28c, but they may have been affected by diagenesis and altered to lower values. Bulk sediment and recrystallised aragonite plot much lower. This divergence in $^{87}Sr/^{86}Sr$ between the aragonite and calcite points is even clearer in the results from Yambol (fig. 4/19iii). Regrettably the calcite points still show a larger variation than should be attributable to the machine alone, although at the time that the samples were run the machine precision was very poor. More likely however, is that the variation is partly due to alteration of the samples and as it seems that Y1Ca2 always gave a value lower than any of the other pieces this has been missed out of the final average which is 0.707734 (Ma8). However, this result can not be considered definitive. The final results for the Bulgarian localities are shown in fig. 4/19iv.

Chapter 5: Dating the rudist beds

5.0 Biostratigraphic dating of Campanian and Maastrichtian strata

Dating a sequence using biostratigraphy involves, ultimately, correlation with the type sequence using indicator fossils. Yet the choice of the type sequence is essentially historical rather than based upon any modern assessment of which would be most suitable and this is responsible for certain problems inherent in biostratigraphic dating.

Most type sequences were originally chosen because they exposed a neatly delimited packet of strata with obvious boundaries such as a major lithological change or unconformity. Thus when the type sequences were matched up, there was frequently a lacuna between the top of one and the bottom of the next - a gap which corresponded to a portion of time unrepresented in the composite column - or else an overlap where the time was doubly represented. The definition of each stage has therefore been extended from the original type sequence by the use of adjacent sections. However, in many cases, the exact limit of the top of the underlying stage which corresponds to the bottom of the overlying one (and by convention the latter is considered the type for the stage boundary) may still be a matter of some controversy. This is often because the two type sequences are of different facies and/or from different faunal provinces and quite different faunas are found in each.

For the two sequences to be matched there must be some biostratigraphic marker present in both places, and it must appear or disappear at the same time in both places. This condition is unlikely to be met in the case of widely separated sequences because of the different environmental conditions in the two areas. Changes in such conditions, (for example a change in climate), often provide the stimulus for the replacement of one form by another. If a form became extinct in its usual area (say Tethys) because of, for example, a general warming in climate, it might well still have existed further north in Boreal latitudes (previously at the edge of its normal geographic range) where it was still sufficiently cool.

The fossils used to correlate the Tethyan and Boreal sequences may well then be diachronous markers.

This history of definition and correlation of the two type stages at the end of the Cretaceous is beset with these very problems. The following account of these comes from the review included in the thesis of Bilotte (1985); the review of the ammonite fauna of the Campanian of Aquitaine by Kennedy (1986); the attempt at correlation of the top of the Campanian with the bottom of the Maastrichtian stratotype by Neumann & Robaszynski (1985); and the general review of Cretaceous stage boundaries by Birkelund *et al.* (1984). References to the original papers (pre-1950) can be found in these works.

The Campanian Stage was created by Coquand (1856 & 57) in his subdivision of d'Orbigny's Senonian Stage of Charentes, Aquitaine into four, the Coniacian, Santonian, Campanian and Dordonian Stages, the original definitions being mainly in terms of the rudist fauna. The Campanian Stage is named after the region of the Grande-Champagne where the type sequence is situated. Coquand considered his Dordonian equivalent to the type Maastrichtian (see below). The terms Campanian and Dordonian were subsequently used by Arnaud in 1877 but with a slightly different meaning, Arnaud's Campanian/Dordonian boundary being slightly lower than Coquand's and coinciding with the appearance of *Orbitoides media*, a definition which has been subsequently (incorrectly) adopted by some authors.

In 1901 De Grossouvre returned to the original definition of the Campanian and Dordonian Stages and subdivided the Campanian into four ammonite zones. De Grossouvre noted the comparison pointed out by Bayle between the rudist bed in the Maastricht sequence (Maastricht tuff) and the Dordonian rudist level in Aquitaine. This had given rise to the suggestion that the Maastrichtian Stage was equivalent to the Dordonian and therefore immediately subsequent to the Campanian. However because the Dordonian could not be separated from the last part of the Campanian using ammonites, De Grossouve concluded that the Dordonian was only a lateral facies of the Campanian and, (which caused great confusion) that therefore the Maastrichtian was only a facies of the Campanian and that the

Campanian extended to the top of the Cretaceous. The age of the Dordonian has important consequences for one of the oldest of the rudist biostratigraphic schemes, that of Toucas (1903, 1904) many of whose "Maastrichtian" fossils are in fact Dordonian (although, according to Bilotte (1985) Toucas' Dordonian is not the same as the original definition). Many subsequent rudist schemes are based on Toucas' work.

The present day ammonite zonation of the type Campanian is based on that of de Grossouvre and is valid not only for Tethys but for the Boreal Province as well. There are two Upper Campanian zones, the lower characterised by *Hoplitoplacenticeras vari* and the upper, end Campanian zone by *Bostrychoceras polyplocum*. A recent subdivision of the type Campanian was made by Platel (1977) who made 8 biozones based on benthic foraminifera. The Dordonian is considered part of the Upper Campanian and no Maastrichtian is recognised. There is also the work of Lambert (1980, 81 - cit. Kennedy, 1986) who made 4 Campanian biozones based on the nannoflora.

The Maastrichtian stage was defined by Dumont in 1849 at Maastricht in southern Limburg, Holland. It was later extended outside the stratotype to include beds with the belemnite *Belemnella lanceolata* Schlotheim and thus the appearance of the ammonite *Hoploscaphites constrictus* Sowerby, which was already a widely used Maastrichtian indicator. Following the work of Jeletsky (1951) in a subdivision of the Upper Campanian and Maastrichtian of the northern Europe using belemnites, most authors are now in agreement about the base of the Maastrichtian Stage at the level of appearance of *B. lanceolata* in this area, a level also marked by a major hiatus. The extended Maastrichtian is formally divided into Lower and Upper portions according to the belemnite stratigraphy (see fig. 4/10), zones which are not of equal length. The type sequence as originally defined by Dumont falls now entirely in the *B. junior* zone, in the lower part of the Upper Maastrictian.

There is no standard ammonite zonation for the Maastrichtian and any Boreal schemes are unsuitable for Tethys. For instance *Hoploscaphites constrictus* which has been used to define the Campanian/Maastrichtian boundary in northern Europe does not occur in Tethys and *Pachydiscus neubergicus* which has been used as an indicator of the Lower

Maastrichtian in Tethys (Wright in Arkell, 1957, cit. Birkelund *et al.* 1984), in Boreal sequences occurs at a level around the Lower/Upper Maastrichtian boundary. Conversely. Other fossils in the Upper Campanian/Maastrichtian northern European sequences are larger and smaller benthic foraminifera, used by Hofker (1966 - cit. Bilotte, 1985) to subdivide the stage, and brachiopods of Surlyk (1970).

There have been various attempts to correlate the bottom of the Maastrichtian type sequence with the top of the Campanian, though none has been entirely satisfactory. Using borehole data to extend the top of the Campanian-Dordonian in Aquitaine, Neumann & Robaszynski, (1985) compared the various different occurrences of macro and microfauna. They cited the presence of the belemnite *Belemnitella mucronata* along with the ammonites *Bostrychoceras polyplocum* and *Scaphites pulcherrimus* in the Upper Campanian of the Campanian type area. In the Maastricht area, where in contrast ammonites are rare and belemnites abundant, the base of the Maastrichtian which is at the level of appearance of *Belemnella lanceolata* is also the level of disappearance of *B. mucronata.* (The zone of *mucronata* is in the lower part of the Upper Campanian though this species extends to the top). They therefore use the disappearance of *B. mucronata* as a synchronous datum to correlate the sequences. The Tethyan larger foraminifer *Orbitoides media* then first appears in the Upper Campanian in Aquitaine while in the Maastricht area *O. media* is present only in the Upper Maastrichtian. There was also little resemblance in apparent ranges of nannofloral species between the areas.

Kennedy (1986) questioned the validity of the belemnite records from Aquitaine. He used ammonites collected from Aquitaine, and the matrix of those specimens was examined for foraminifera (by M. Neumann) to identify the bed from which they came. However, because records of those ammonites in the boreal sequences were so sparse and incomplete, no final conclusion was reached as to a correlation between the top of the Campanian sequence as based on Tethyan benthic foraminifera/ammonites and the bottom of the Maastrichtian according to the boreal belemnite stratigraphy.

Thus two schools of thought remain as to the age of the Dordonian. One view, strengthened by the work of Platel (1977) with smaller benthic foraminifera (and with the support of most ammonite workers, notably Kennedy), sees the Dordonian as part of the Upper Campanian. The other school, exemplified by Seronie-Vivien (1972 - cit. Philip & Bilotte, 1985) by using smaller and larger benthic foraminifera (and supported by the rudist workers Philip & Bilotte, 1985, but see under Aquitaine for full discussion) sees the Dordonian as equivalent to the lower part of the Maastrichtian. I find the former arguments stronger than the latter.

In practice many Tethyan stratigraphers have ceased to use the type sequences for the Campanian and Maastrichtian as standards and are using versions of the planktonic foraminiferal stratigraphy for the equatorial Atlantic based on ODP cores (figs. 5/1). Although intercalations of planktonic foraminfera in rudist sequences are not common, benthic foraminifera usually co-occur and may be used as intermediaries to the local planktonic foraminiferal stratigraphy. There are various different schemes for the planktonic foraminiferal stratigraphy, but all use a *calcarata* zone at the top of their Campanian and a *mayorensis* zone at the top of the Maastrichtian. There seems to be a certain amount of agreement between different authors upon the length of the *mayorensis* zone relative to the total Maastrichtian and of the *calcarata* zone relative to the total Campanian (with the Campanian/Maastrichtian boundary placed at the extinction of *Globotruncanita calcarata* and the Campanian/Santonian at the appearance of *G. elevata* and *stuartiformis*). The most frequently used subdivision of the Maastrichtian by planktonic foraminifera is tripartite and has caused many authors to write of a lower, middle and upper Maastrichtian.

Planktonic foraminifera are not frequent in the type Maastrichtian sequence, so the planktonic foraminiferal and belemnite stratigraphies cannot be correlated directly (Birkelund *et al.*, 1984). It is now thought that *G. calcarata* became extinct fairly close to the boundary as defined by ammonites, ie. ranging to just above the lowest occurrence of *Bostrychoceras polyplocum* in North Africa (Marks, 1984 cit. Birkelund *et al.*, 1984), although this is not a first order correlation. Thus in this area at least, it seems that the *calcarata* extinction is within the *B. polyplocum* ammonite zone, equivalent to somewhere in the *langei/minor*

The other school, exemplified by Seronie-Vivien (1972 - cit. Philip & Bilotte, 1985) by using smaller and larger benthic foraminifera (and supported by the rudist workers Philip & Bilotte, 1985, but see under Aquitaine for full discussion) sees the Dordonian as equivalent to the lower part of the Maastrichtian. I find the former arguments stronger than the latter.

In practice many Tethyan stratigraphers have ceased to use the type sequences for the Campanian and Maastrichtian as standards and are using versions of the planktonic foraminiferal stratigraphy for the equatorial Atlantic based on ODP cores (figs. 5/1). Although intercalations of planktonic foraminfera in rudist sequences are not common, benthic foraminifera usually co-occur and may be used as intermediaries to the local planktonic foraminiferal stratigraphy. There are various different schemes for the planktonic foraminiferal stratigraphy, but all use a *calcarata* zone at the top of their Campanian and a *mayorensis* zone at the top of the Maastrichtian. There seems to be a certain amount of agreement between different authors upon the length of the *mayorensis* zone relative to the total Maastrichtian and of the *calcarata* zone relative to the total Campanian (with the Campanian/Maastrichtian boundary placed at the extinction of *Globotruncanita calcarata* and the Campanian/Santonian at the appearance of *G. elevata* and *stuartiformis*). The most frequently used subdivision of the Maastrichtian by planktonic foraminifera is tripartite and has caused many authors to write of a lower, middle and upper Maastrichtian.

Planktonic foraminifera are not frequent in the type Maastrichtian sequence, so the planktonic foraminiferal and belemnite stratigraphies cannot be correlated directly (Birkelund *et al.*, 1984). It is now thought that *G. calcarata* became extinct fairly close to the boundary as defined by ammonites, ie. ranging to just above the lowest occurrence of *Bostrychoceras polyplocum* in North Africa (Marks, 1984 cit. Birkelund *et al.*, 1984), although this is not a first order correlation. Thus in this area at least, it seems that the *calcarata* extinction is within the *B. polyplocum* ammonite zone, equivalent to somewhere in the *langei* Campanian belemnite zone. The foraminiferal boundary is therefore slightly lower than the belemnite boundary. Incidently another definition of the Campanian/Maastrichtian boundary based on the extinction of the widespread coccolith *Quadrum trifidum*, falls well above the

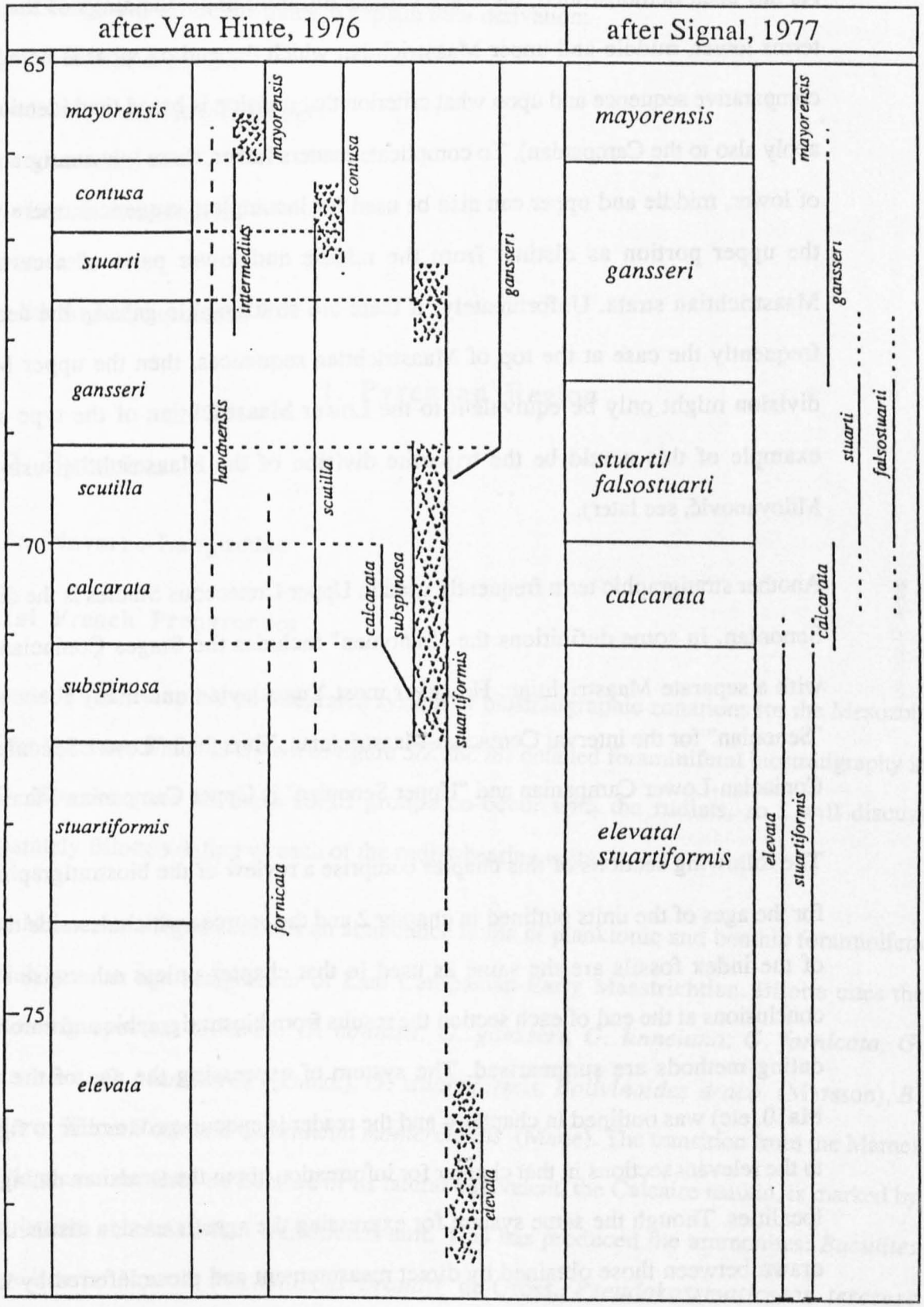


Figure 5/1. Planktonic foraminiferal zonation schemes used for Atlantic and Mediterranean sequences.

base of the Lower Maastrichtian as defined by the planktonic foraminifera (cit. Birkelund *et al.*, 1984).

As has been demonstrated, there are various different understandings of the usage of the terms lower, middle and upper Maastrichtian which depend on what is being used as the comparative sequence and upon what criterion that division is based (and identical arguments apply also to the Campanian). To complicate matters futher, these lithostratigraphic divisions of lower, middle and upper can also be used for incomplete sequences, merely to describe the upper portion as distinct from the middle and lower parts of a certain stack of Maastrichtian strata. Unfortunately, if there are stratigraphic gaps in the sequence, as is frequently the case at the top of Maastrichtian sequences, then the upper Maastrichtian division might only be equivalent to the Lower Maastrichtian of the type sequence (an example of this would be the tripartite division of the Maastrichtian using rudists by Milovanović, see later).

Another stratigraphic term frequently used in Upper Cretaceous Studies is the division called Senonian. In some definitions the "Senonian" includes the Stages Coniacian-Campanian with a separate Maastrichtian. However most Yugoslavian and many French authors use "Senonian" for the interval Coniacian-Maastrichtian. Thus their "Lower Senonian" is usually Coniacian-Lower Campanian and "Upper Senonian" is Upper Campanian-Maastrichtian.

The following sections of this chapter comprise a review of the biostratigraphic arguments for the ages of the units outlined in chapter 2 and the sources which describe the occurrence of the index fossils are the same as used in that chapter unless otherwise stated. In the conclusions at the end of each section the results from biostratigraphic and chronostratigrahic dating methods are summarised. The system of expressing the age of the units (Ca20, Ma10, etc) was outlined in chapter 4 and the reader is encouraged to refer to figure 4/13 and to the relevant sections in that chapter for information about the strontium dating of particular localities. Though the same system for expressing the ages is used, a distinction should be drawn between those obtained by direct measurement and those inferred by knowledge of the age of the zone. To indicate the latter, the symbol ≈ (meaning "implies") is placed in

front of the date. The final answer for the most probably age of the unit, obtained considering the evidence for the under- and overlying units is written in bold. On the accompanying diagram these dates are placed in the right hand column and the following symbols placed before the dates to explain their derivation:

S = Sr isotope derived

p = from planktonic foraminifera

a = ammonites

b = benthic foraminifera

r = rudists

l = lithological correlation

1. Pyrenean Region

1.1 Pyrenees

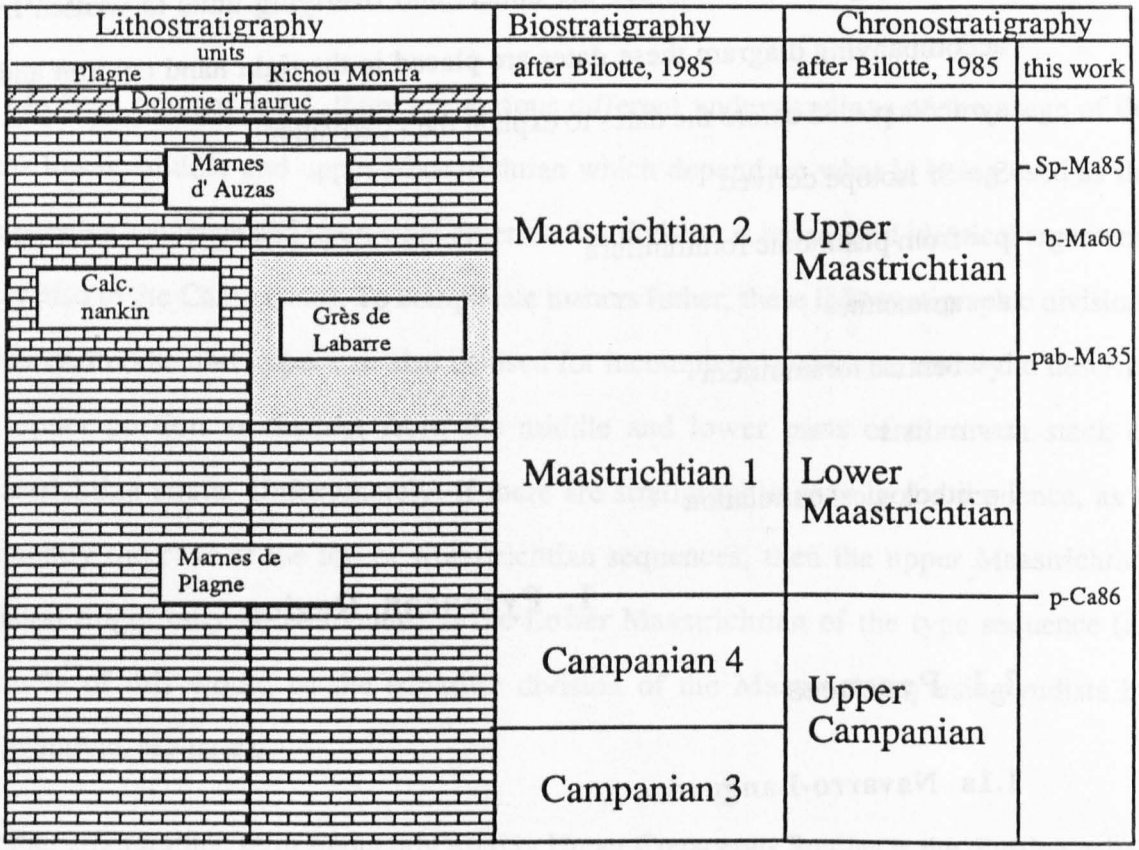
1.1a Navarro-Languedoc

1.1ai French Prepyrenees

Bilotte (1985) compiled an integrated system of biostratigraphic zonations for the Mesozoic of the Pyrenees which is shown in figure 5/2 and his detailed foraminiferal biostratigraphy in 5/3. However, not all these fossil groups co-occur with the rudists, so I will discuss separately Bilotte's dating of each of the rudist-bearing units.

The Marnes de Plagne contains an abundance fauna of planktonic and benthic foraminifera which give an age assignment of Late Campanian-Early Maastrichtian. Bilotte cites the following species: *G. arca, G. contusa, G. gansseri, G. linneiana, G. fornicata, G. ventricosa, G. plummerae* (Gand.), *G. stuartiformis, Bolivinoides draco* (Marsson), *B. miliaris* Kilt et Koch and *Gavelinella monterelensis* (Marie). The transition from the Marnes de Plagnes to the Grès de Labarre or its lateral equivalent, the Calcaire nankin, is marked by a carbonate and fossil-rich transitional unit. This has produced the ammonites: *Baculites leopoliensis* Nowak, *Pachydiscus brandti* de Gross., *Pseudokossmaticeras tercense* (Seunes) and *Sphenodiscus ubaghsi* de Gross. which according to J. Kennedy (cit. Bilotte,

French Prepyrenees



Biostratigraphic zonations of Bilotte, 1985				
Zone	Rudists	Benthic Forams	Planktonic Forams	Ammonites
Maas. 2	*Hlla lapeirousei*; *Hlla castroi*; *Htes lamarcki*	*Siderolites calcitrapoides*; *Orbitoides apiculata*	*Racemigumbelina fruticosa*	*Hoploscaphites constrictus*
Maas. 1	*Hippurites radiosus*	*Orbitoides media*	*Globotruncana contusa*; ?	*Sphenodiscus ubaghsi*
Camp. 4	?	*Pseudosiderolites vidali*	*Globotruncana calcarata*	*Bostrychoceras polyplocum*
Camp.3			*Globotruncana stuartiformis*	*Hoplitoplacenticeras vari*

Figure 5/2

Pyrenees

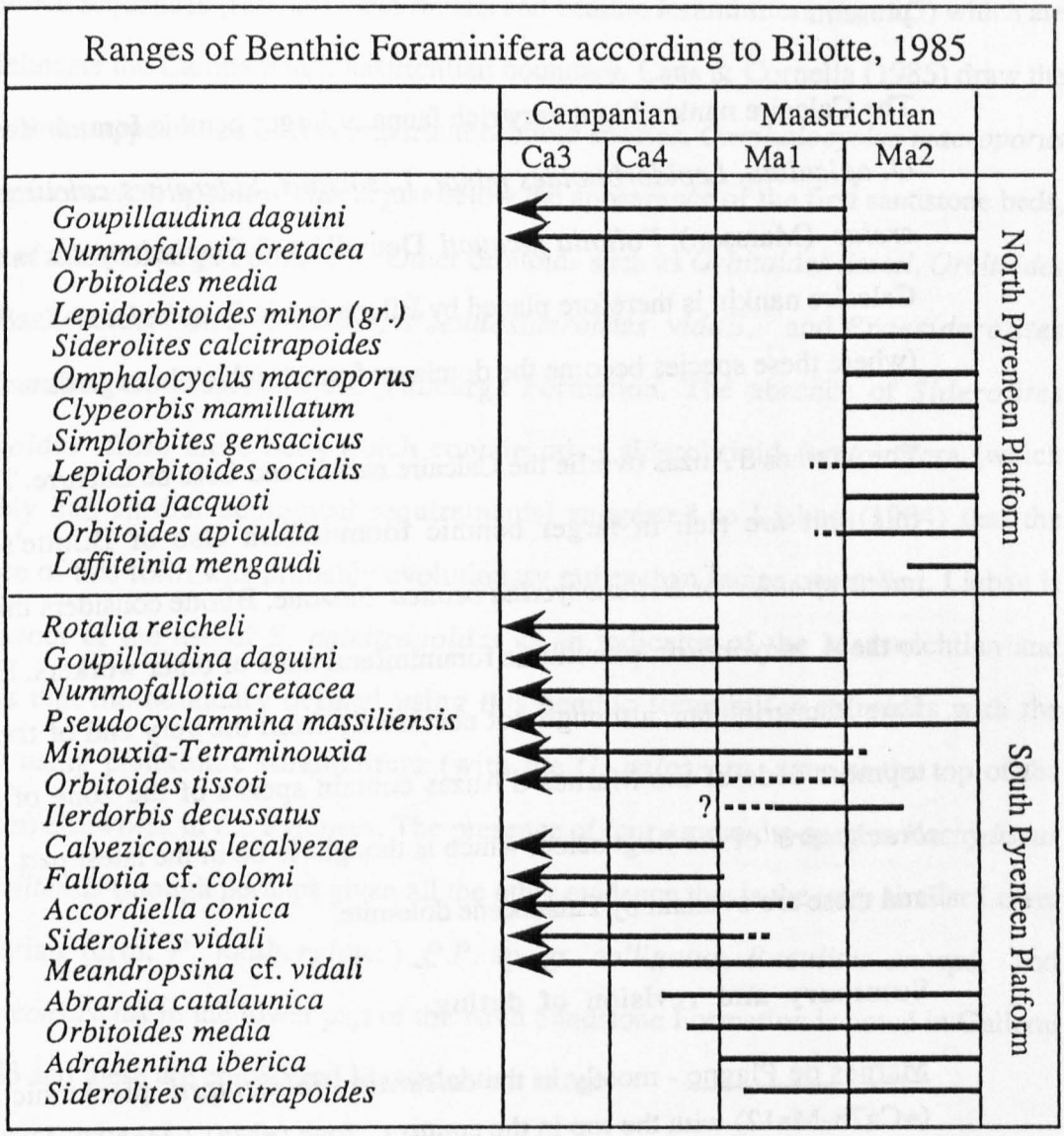


Figure 5/3. Ranges of benthic foraminifera in the French Pyrenees and Catalonia, *sensu* Bilotte, 1985

1985) makes the unit Early Maastrichtian in age. The larger benthic foraminifera *Orbitoides apiculata, Siderolites calcitrapoides,* and *Lepidorbitoides gr. minor* and *Fallotia* sp. are also present.

The Calcaire nankin has a very rich fauna of larger benthic foraminifera: *Orbitoides media, O. apiculata, Lepidorbitoides minor, L. socialis, Siderolites calcitrapoides, Planorbulina cretae* (Marsson), *Fallotia jacquoti* Douvillé and *Omphalocyclus macroporus* Lmk. The Calcaire nankin is therefore placed by Bilotte in his *O. apiculata - S. calcitrapoides* biozone (where these species become the dominant forms), which he regards as Late Maastrichtian.

The Marnes d'Auzas overlie the Calcaire nankin and Grès de Labarre. The limestone beds of this unit are rich in larger benthic foraminifera also of Bilotte's. *O. apiculata - S. calcitrapoides* or *Hellenocyclina beotica* biozone. Bilotte considers this roughly equivalent to the *A. mayorensis* planktonic foraminiferal zone of other workers. He considers that it is Late Maastrichtian, although not necessarily from the very end of the Maastrichtian. The topmost beds of the Marnes d'Auzas contain spores of the zone of *Septorella ultima - brachycera* of the Rognacien, which is thought to be in the latest part of the Maastrichtian, and these are overlain by Palaeocene dolomite.

Summary and revision of dating

Marnes de Plagne - mostly in the *calcarata - falsostuarti* planktonic foraminiferal zones (≈Ca78-Ma12) with the top in the *contusa* zone (≈Ma12-Ma50?). **Ca80-Ma35**

Marnes de Plagne/Calcaire nankin transition - ammonites of (Boreal?) Early Maastrichtian age (≈Ma0-Ma35). **Ma35**

Calcaire nankin - benthic foraminifera which have a total range of the entire planktonic foraminiferal Maastrichtian (≈Ca86-Ma100) but in the French Pyrenees are more abundant in the upper part of this range. **Ma35-Ma60**

Marnes d'Auzas - in the same *O. apiculata-S.calcitrapoides* biozone also with *Hellenocyclina beotica* whose range is roughly equivalent to that of the *mayorensis* planktonic foraminiferal biozone in the Pyrenees. Sr-isotope dates for the rudist levels gave results averaging Ma74, though given that the rudist beds are overlain by a substantial thickness of Cretaceous strata, the topmost levels are probably not younger than Ma85. **Ma60-Ma100**

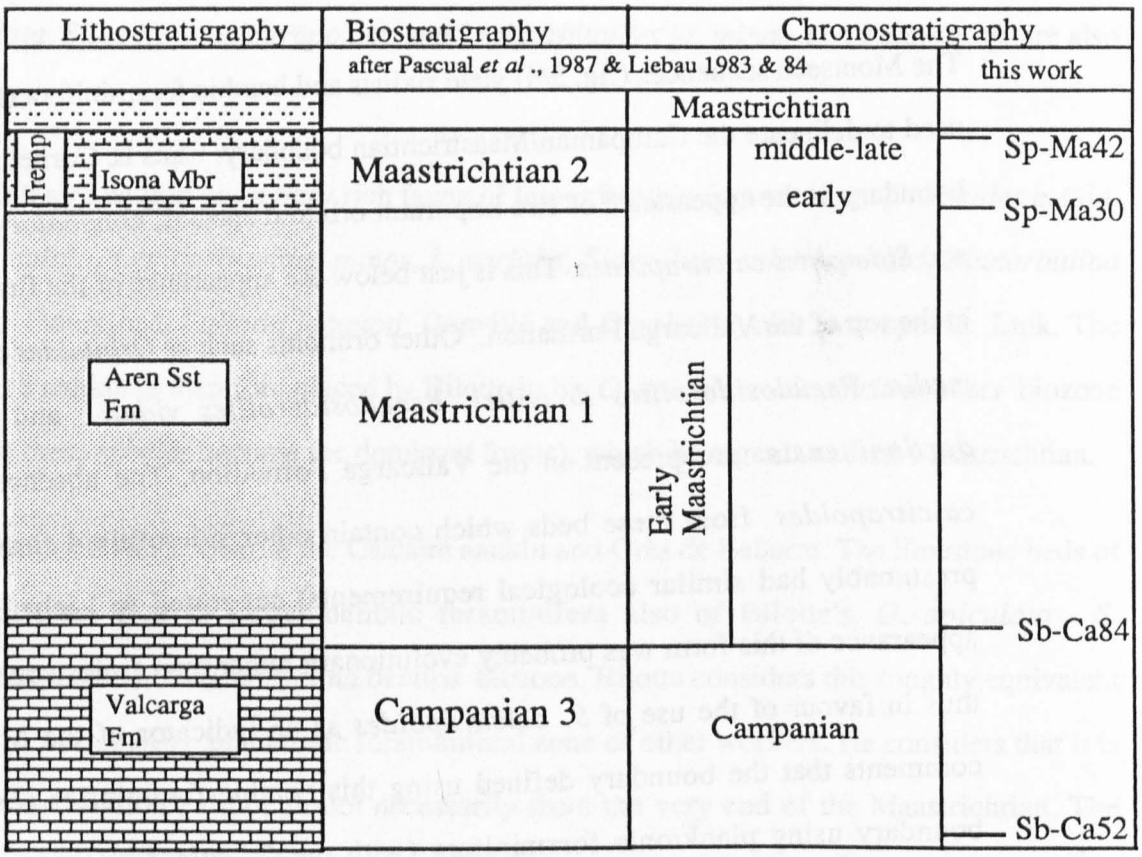
1.1bii Central Southern Pyrenees

The Montsech sequences (fig. 5/4) yield rudists and benthic foraminifera (fig. 5/5) which are used to delineate the Campanian/Maastrichtian boundary. Caus & Cornella (1985) draw the boundary at the appearance of two important orbitoid species, *Omphalocyclus macroporus* and *Siderolites calcitrapoides*. This is just below the appearance of the first sandstone beds, at the top of the Vallcarga Formation. Other orbitoids such as *Orbitoides tissoti, Orbitoides media, Pseudosiderolites douvillei, Pseudosiderolites vidali,* and *Praesiderolites dordoninensis* are present in the Vallcarga Formation. The absence of *Siderolites calcitrapoides* from these beds which contain other siderolitinid foraminifera (which presumably had similar ecological requirements) suggested to Liebau (1984) that the appearance of this form was probably evolutionary rather than facies controlled. Liebau is thus in favour of the use of *S. calcitrapoides* as an indicator of the Maastrichtian and comments that the boundary defined using this benthic foraminifer coincides with the boundary using planktonic foraminifera (with the *G. calcarata* zone at the top of the Campanian) elsewhere in the Pyrenees. The presence of four ammonite species *Pachydiscus (P.) gollevillensis* (though perhaps given all the other evidence this is the very similar Lower Maastrichtian form, *P. neubergicus*), *P.P.* sp. gr. *colligatus, Baculites anceps,* and *Scaphites constrictus* in the lower part of the Aren Sandstone Formation is noted in Gallemi *et al.*, 1983 and these are considered Maastrichtian in age.

The Tremp Formation, which overlies the Aren Sandstone has been dated by Liebau (1984) from its outcrop in the Tremp Basin by the intercalated layers with planktonic and small benthic foraminifera. He suggested two zones, one of early, Early Maastrichtian and the other of middle-late, Early Maastrichtian age and these are tabulated in figure 5/6.

The dating of the rudist beds primarily by foraminifera has been adopted by most rudist workers. For instance in the work of Pascual *et al.*, 1987 the benthic foraminiferal Campanian/Maastrichtian boundary separates the rudist species of the Campanian zone Ca_3 from those of the Maastrichtian Ma_1. Rudists of the Tremp Formation are considered as a separate assemblage Ma_2 which includes the appearance of one new form *Hippuritella*

Spanish Pyrenees



Biostratigraphic zonations used in Pascual *et al.*, 1987 and Liebau, 1984

Zone	Rudists	Benthic Forams	Planktonic Forams
Maastrichtian 2	*Hippuritella castroi* *Biradiolites chaperi* *Hippurites radiosus*	*Siderolites calcitrapoides* *Lepidorbtoides socialis*	*Globotruncana gansseri* *Gl. arca Gl. stuarti Gl. falsostuarti*
Maastrichtian 1	*Hlla lapeirousei* *Radiolitella pulchellus* *Hippurites radiosus*	*Omphalocyclus macroporus*	?
Campanian 3	*Hippurites vidali* *Praetes. boucheroni*	*Orbitoides media* *Pseudosiderolites vidali*	?

Figure 5/4

Spanish Pyrenees

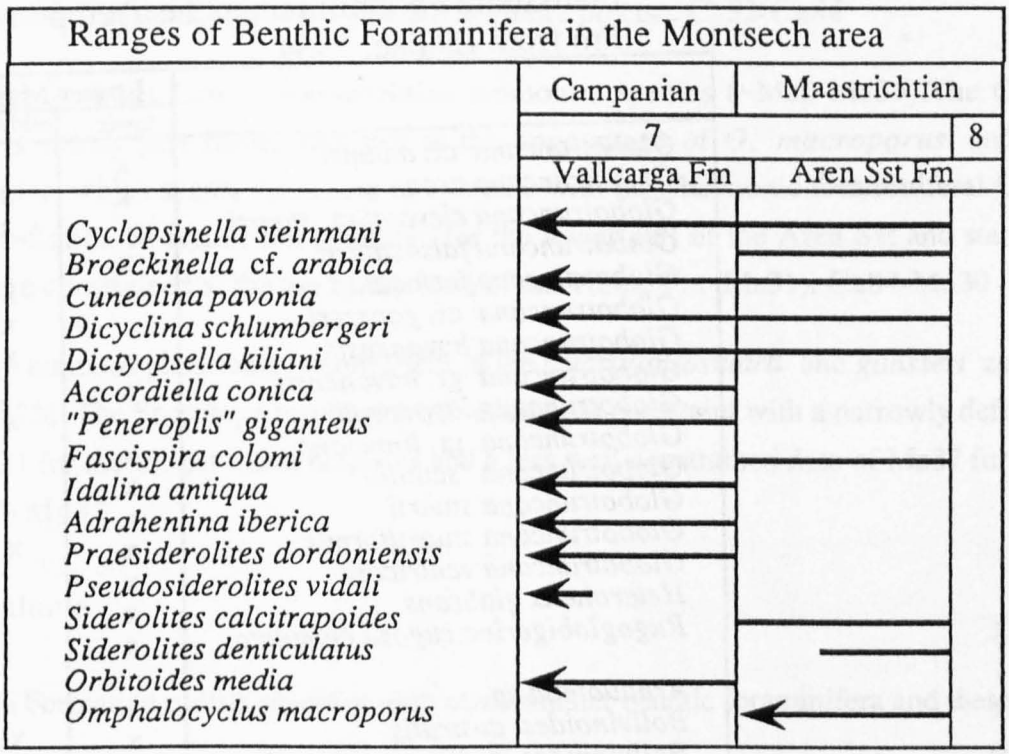


Figure 5/5

Planktonic Foraminifers in the Tremp Fm from Liebau, 1984		
	Lower Maas	
	lower	mid-upper
Globotruncana cf. *adamsi*	x	
Globotruncana arca	x	x
Globotruncana elevata/ cf. *stuarti*		x
Globotruncana falsostuarti	x	
Globotruncana fornicata	x	x
Globotruncana cf. *gansseri*		x
Globotruncana havanensis	x	x
Globotruncana gr. *havanensis*	x	
Globotruncana lapparenti		x
Globotruncana gr. *linneiana*	x	
Globotruncana "scutilla"	x	
Globotruncana stuarti	x	
Globotruncana stuartiformis	x	x
Globotruncana ventricosa	x	
Heterohelix glabrans	x	
Rugoglobigerina rugosa cumulata	x	
Arnaudiella sp.	x	
Bolivinoides australis	x	x
Bolivinoides decoratus australis	x	x
Bolivinoides draco draco		x
Bolivinoides draco miliaris	x	x
Bolivinoides verrucosus		x
Bolivinoides peterssoni		x
Bolivinoides decoratus decoratus		x
Dictyopsella sp.		
Kingmaina hagenowi		
Laffitteina marsicana		
Neoflabellina praereticulata	x	
Oertliella horridula	x	
Pseudoguembelina costata	x	
Pseudoguembelina browni	x	
Clypeorbis mamillatus	x	
Lepidorbitoides gr. *socialis*	x	
Siderolites calcitrapoides	x	x
Siderolites denticulatus		x

Figure 5/6

castroi . Both Ma_1 and Ma_2 are regarded as Early Maastrichtian by Pascual *et al.* (using Liebau's dating evidence).

Summary and Revision of dates

top of Vallcarga Fm - has certain orbitoids thought to be from the planktonic foraminiferal late Campanian. Sr-isotope results agree but are more precise. **Ca52-Ca84**

Aren Sst Fm - yields Lower Maastrichtian ammonite species (≈Ma0-Ma35).The C/M boundary is drawn just inside this Fm at the appearance of *O. macroporus* and *S. calcitrapoides* which seems elsewhere to coincide with the planktonic foraminiferal C/M boundary (≈Ca86). Sr results are available for the lower part of the Aren Sst and start at Ca80 and are constrained at the top by the base of the Tremp Fm (Ma31). **Ca84-Ma30**

Tremp Fm - contains planktonic foraminifera of the *stuarti/falsostuarti* and *gansseri* zones (≈Ca86-Ma75). The Sr-isotope results provide additional constraint with a narrowly defined age of Ma31 for the lowest rudist horizons and a less well constrained date of Ma37 for the top. **Ma30-Ma42**

1.1b Catalonia

In the Bona Formation rudists co-occur with some smaller benthic foraminifera and these are overlain by beds with *Lepidorbitoides gr. minor* and *Siderolites calcitrapoides* assigned a general Maastrichtian age by Bilotte (1985). The overlying Formation de Oden which is lacustrine-continental contains palynomorphs from the *Septorella brachycera* zone of purported Upper Maastrichtian age. The Grès du Mas Gaou is in a similar situation, overlain by barren marls and continental red beds and is also considered Maastrichian in age.

In the Pedraforca Nappe, the "Calcaires de Terradets" or Vallcarga Formation rudists are found alongside larger and smaller benthic foraminifera. Most of this is Lower Campanian according to the rudists, ammonite and synchronous appearance of *Pseudosiderolites vidali* and *Orbitoides tissoti* . The upper part is regarded as Maastrichtian due to the presence of *Siderolites calcitrapoides*, but the boundary is not established precisely.

Summary of dating

Bona Fm - **≈Ca86-Ma60**

Vallcarga Fm of Pedraforca nappe - **≈Ca20-Ma0**

1.2 Aquitaine

The age of the Dordonian rudist level of Aquitaine was discussed in the introduction to this chapter but it is also worth mentioning the arguments for the age of this unit which are based on the rudists presented in Philip & Bilotte, 1985. According to these authors, Coquand's Dordonian covers only his last rudist level (assise B) which Coquand described as characterised by *Hippurites radiosus* , *Praeradiolites cylindraceus* and *Lapeirousia jouanneti.*

In the Maastricht tuff there were 5 species reported by Van de Geijn in 1843 (cit. Philip & Bilotte, 1985). Two of these, *Praeradiolites cremersi* and *P. faujasi* are endemic to Maastricht. Of the other three, *Hippuritella lapeirousei* is associated with *Hippurites radiosus* in the Dordonian according to Toucas (1903 - cit. ibid.); *Praeradiolites hoeningshausi* is known in the Upper Campanian of Aquitaine (Toucas, 1907, cit. ibid.) but also in beds adjacent to those of the *H. radiosus* level (Philip & Bilotte, 1985); *Biradiolites royanus* is present in the uppermost Campanian and in the Dordonian. Thus of the 5 species reported in that work from Maastricht, 3 existed in the Dordonian.

However, these data have now been superceeded by recent finds of these species in other areas and revision of their ages (this work). This reveals that these three species are now known elsewhere in Tethys in beds from the Early Campanian to Early Maastrichtian. Moreover a comparison to their ranges in Tethys is probably more valid than a comparison to the range in Boreal latitudes which are part of quite a different faunal province.

Summary of dating

Dordonian - **≈Ca80-Ca90**

1.3 Sardinia

The Tertiary conglomerates of the **Conglomerat de Cuccuru 'e Flores** at Sovana have produced three hippuritid rudists which, according to Busulini *et al.* (1984) are Campanian

in age. The conglomerate from Lanaitto contains blocks thought to be from the upper part of the Maastrichtian and these contain the rudist *Hippurites cornucopiae* (Defrance) and the foraminifera *Orbitoides* sp. and rare *Globotruncana* ex gr.*linneiana* (d'Orbigny). The presence of *H. cornucopiae* was noteworthy as it was known only from the Central Mediterranean Province (Philip, 1983 & Camoin, 1983 both cit. Busulini *et al.*, 1984) and was used as evidence for the Eastern Sardinian carbonate platform having been in a position intermediate between those of the Pyrenees and those of the Apulian Plate.

Summary of dating

insufficient evidence for comment

2. Periadriatic Region

2.1 Dinaric Platform

2.1a S. Slovenia (Nanos, Dolenja Vas)

The topmost beds of rudist limestone are best known from M. Nanos (see fig. 5/8) where they have been described in the works of Mario Pleničar. The rudist assemblage was always thought of as Maastrichtian because of the similarity of the assemblage to that of the so-called Vrbovac beds of eastern Serbia (of Milovanović & Grubić 1972). According to Pleničar (1979) the most significant components of the fauna to occur in both areas are the hippuritids *Vaccinites braciensis* Sladić-Trifunović, *Vaccinites giordani* Pirona and *Vaccinites atheniensis* Ktenas as well as the radiolitid genus *Pseudopolyconites* and the enigmatic *Sabinia*. Unfortunately many rudists described by Pleničar have been dated solely by comparison with their reported ranges elsewhere and their stratigraphic level seems to be unrecorded. However, *Joufia, Vaccinites* and *Pseudopolyconites* are known from at least 60m from the top of the limestone (Skelton, pers. comm.) at a level where the foraminifera *Keramosphaerina tergestina* is recorded (Pleničar, 1989, pers. comm.).

S. Slovenia

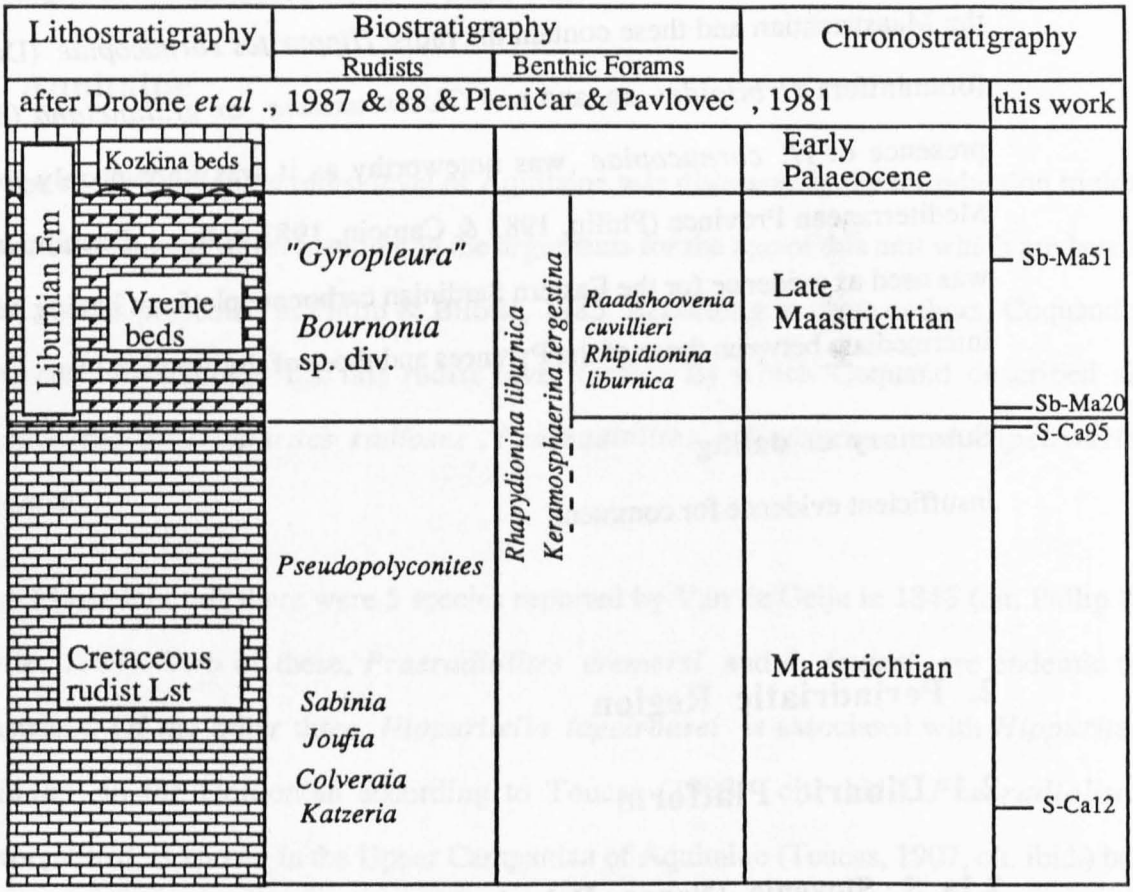


Figure 5/7

?

According to Pleničar & Pavlovec (1981) the foraminifera *Keramosphaerina tergestina* Stache, *Montcharmontia apenninica* De Castro, *Minouxia* cf. *lobata* Gendrot (Redka), *Dicyclina schlumbergeri* Munier-Chalmas, *Accordiella conica* Farinacci (Redka) and, interestingly, *Rhapydionina liburnica* (Stache) are also found in the main rudist unit (though not neccessarily all at M. Nanos). Many of these are also recorded in the Vreme beds. Bignot (1972) records the following orbitoids from just below the Scaglia contact on Nanos: *Orbitoides media, O. apiculata, Lepidorbitoides minor, L. socialis,* and *Omphalocyclus macroporus* , which for him would give the top of the Nanos rudist limestone a Late Maastrichtian age. He recorded *K. tergestina* from a lower horizon at Nanos.

There are several other outcrops of rudist limestone in eastern Friuli - southern Slovenia - Istria where the rudist limestone with orbitoids is overlain by Scaglia Rossa. Three other localities are recorded by Bignot (1972): M. Sabotin, a section at Plave on Trnovški Gozd and around Kališe. At M. Sabotin, the limestones are breccias, thought by Bignot to be lower Senonian but with material of Maastrichtian age between the blocks. [However, there are recent records of *Sabinia* from this locality (G. Tunis, pers. comm., 1987) and I think that it is probably equivalent to the the top of the limestone at M. Nanos and M. Jouf]. Bignot cites *Orbitoides media, Lepidorbitoides* sp., *Siderolites calcitrapoides* and *S. denticulatus* . Significantly these are overlain by a Scaglia Rossa with the planktonic *Globotruncana* species: *G. arca, G.* cf. *conica, G.* cf. *stuarti* and *G.* cf. *stuartiformis* of Maastrichtian [and almost certainly fairly early Maastrichtian] age.

The Vreme beds, beds of Cretaceous limestone which overlie the rudist beds, are not present at Nanos, but can be found at other localities in Slovenia, Istria and eastern Italy. According to Bignot (1972) the lower part of the Liburnian beds contains the foraminifera *Rhapydionina liburnica, Rhipidionina liburnica* and *Raadshoovenia cuvillieri* which are found only in the marine beds (as distinct from those with charophytes which occur in the Lower as well as characterising the Middle Liburnian Formation). He considers these foraminifers to have exactly the same stratigraphic range as each other throughout the Istrian Peninsula and surrounding area. Bignot considers their range to be middle Senonian, ie.

Campanian, but this is not a view shared by most rudist authors (see for instance discussion in sections on Croatia, or Salento). They consider *R. liburnica* diagnostic for Late Maastrichtian strata following the work of Fleury (1973, 1980) in Greece and its occurrence there above the zone of *Omphalocyclus macroporus* (cit. Drobne *et al.*, 1988). Pleničar & Pavlovec (1981) also cited *Rhapydionina liburnica* from intercalations in the main rudist limestone with *K. tergestina* co-occurring with the rudists at the same stratigraphic level. If this record can be confirmed this is particularly interesting because, according to Bignot (1972) *K. tergestina* always occurs below *R. liburnica* and was thought to be Santonian in age in Istria and the surrounding area.

The Vreme beds also contain the rudist which Pleničar calls *Gyropleura* . Pleničar (1979) placed these beds in the Danian, which presumably implied that the rudists ranged into the Tertiary, though Pleničar & Pavlovec (1981) later regarded them as Late Maastrichtian. Beds overlying the Vreme beds are distinguished by the absence of rudists or the foraminifer *R. liburnica.* They are known as the Kozina beds which form the middle part of the Liburnian Fm and are Tertiary in age. At Dolenja Vas, the rudist limestones are overlain apparently conformably by the Liburnian Fm. Drobne *et al.*, regarded the Kozkina beds at Dolenja Vas as Lower Palaeocene, but they were not sure that strata representing the lowermost Palaeocene were present. The sequence could still thus be incomplete over the Cretaceous/Tertiary boundary.

Summary and revision of dating

About 50m from top of Nanos sequence - together the rudists and foraminifera indicate an early Campanian-middle Maastrichtian age. A horizon about 50m from the limestone/Scaglia contact on the SW side of the mountain, about 10m stratigraphically above biostromes with *Vaccinites, Joufia* and *Pseudopolyconites,* and containing the foraminifer *K. tergestina,* was dated with Sr-isotopes. This shows the rudist assemblage to be of earliest Campanian age at this locality which proves that *K. tergestina* is "Lower Senonian" here. **Ca12 -**

Top of Cretaceous limestones at Nanos - Contains orbitoids including *S. calcitrapoides, L. socialis* and *O. macroporus.* Material from a horizon with orbitoids was dated as Ca95. This shows that *O. macroporus* has the same range as the other "Maastrichtian" orbitoids and can not be considered an exclusively Late Maastrichtian form. This level also outcrops

on M. Sabotin where it is overlain by strata with foraminifera of the *calcarata* or *stuarti/falsostuarti* (≈Ca78-Ma12). - **Ca95**

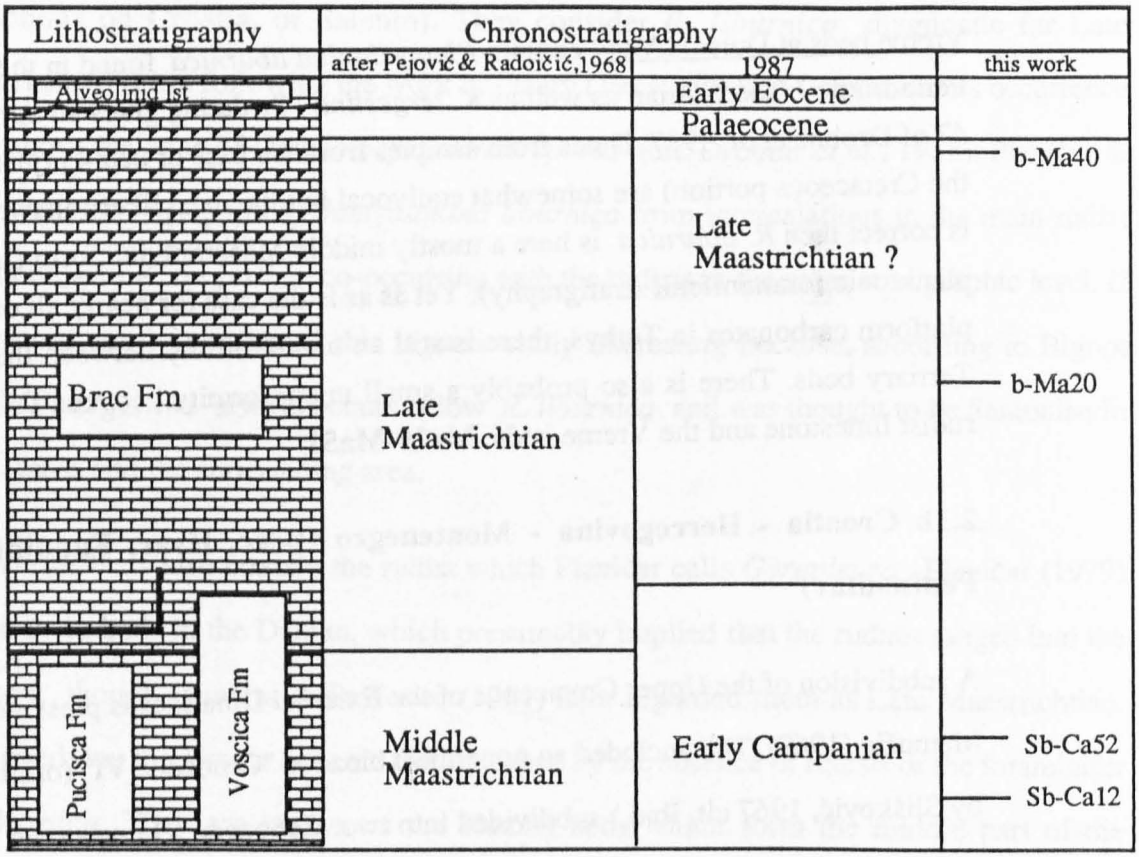
Vreme beds at Dolenja Vas - contain *Rhapydionina liburnica* found in the upper part of the Periadriatic Maastrichtian as well as *K. tergestina* . Sr-dating gives an age of Ma34 for bed 47 of Drobne *et al* 1987. Dates from samples from the base of bed 45 (just below the top of the Cretaceous portion) are somewhat equivocal but the most likely answer is Ma49. If this is correct then *R. liburnica* is here a mostly middle Maastrichtian form (in the sense of the planktonic foraminiferal stratigraphy). Yet as as is the case for nearly all other sequences of platform carbonates in Tethys, there is still an unconformity between the Cretaceous and Tertiary beds. There is also probably a small unconformity between the top of the main rudist limestone and the Vreme beds. **Ma20-Ma51**

2.1b Croatia - Hercegovina - Montenegro (Brac, Hvar, Fundinia, Peljašac Peninsular)

A subdivision of the Upper Cretaceous of the External Dinarides is presented by Polšak and Mamužić (1969). This included an uppermost biozone "Cenozone VI" (originally established by Slišković, 1967 cit. ibid.) subdivided into two. Cenozone VIa was seen by these authors as Late Campanian-Early Maastrichtian and Cenozone VIb as Middle and Late Maastrichtian. The age assignment is ultimately derived from the work of Milovanović (Milovanović, 1934b, 60) and his definition of *Pironaea* beds of eastern Serbia as Early, Middle and Upper Maastrichtian (see discussion under that section). Cenozone VIa contains *Vaccinites loftusi*, the supposed ancestor of the genus *Pironaea* and Cenozone VIb, *Pironaea polystyla milovanovici*. With more recent finds, and a realisation that the evolutionary scheme of *Pironaea* could equally well be ontogenetic, the subdivision of this Cenozone for the localities listed in Polšak and Mamuzić, 1969 now seems invalid.

Cenozone VIb presumably originally corresponded to the **Pučišća Formation** of Pejović and Radoičić (1987) on Brač Island (see fig. 5/9). The rudist assemblage of the Pučišća formation includes the hippuritid *Pironaea* cf. *milovanovici*, which following the work of Milovanović should have been considered Late Maastrichtian. However, because there is a substantial thickness of rudist limestone which overlies these beds, many authors were reluctant to consider it all Late Maastrichtian and compromised on a Middle Maastrichtian age (Pejović & Radoičić, 1968 cit. Pejović & Radoičić, 1987) for these beds. The range of

Brač Island, Croatia



Biostratigraphy of Brač Island after Pejović & Radoičić, 1987

Lithostratigraphic unit		Rudists	Benthic foraminifera	
Brač Formation		*Radiolites* *Bournonia* *Pseudopolyconites*	*Rhapydionina liburnica* *Laffiteina mengaudi*	
			Raadshoovenia *Murciella*	*Keramosphaerina tergestina*
Pučišća Formation	Voščića Formation	*Pironaea polystyla milovanovici* *Joufia* *Sabinia*	*Siderolites vidali* *Orbitoides tissoti*	

Figure 5/8

Vaccinites atheniensis then had to be extended because at other localities on Brač it was thought to be Santonian. The co-occurring rudist genus, *Colveraia* was therefore also regarded as Maastrichtian. The beds with *P. milovanovici* - now of the Pučišća fm - are considered the lateral equivalent of those containing the foraminifera *Keramosphaerina tergestina* - of the Vočisća Formation. Thus *K. tergestina* gained a reputation for a range into the Maastrichtain at least according to Yugoslavian workers (Buser, 1965 cit. Pejović & Radoičić, 1987).

Pejović & Radoičić (1987) have since called into question the strength of the dating of the Brač Island beds based on *Pironaea* and have suggested that the occurrence of the usually 'Lower Senonian' *K. tergestina* is a more reliable basis for dating the Pučišća fm. Extra evidence for a more likely Campanian age is provided by the foraminifera *Orbitoides tissoti* which, they claim, has a reputation, for occurrence in beds "positively older that uppermost Campanian". The foraminifer *Siderolites vidali* is also present. In conclusion, they prefer an earlier age in the Early Campanian (or even uppermost Santonian is not ruled out) for the beds on Brač with *P. milovanovici*. The last *Keramosphaerina* are found in beds with *Distefanella* cf. *radoicicae*, considered a marker level throughout Brač. The disappearance of *Keramosphaerina* is therefore thought to be an evolutionary event, not simply due to a facies change.

The topmost beds from Hvar have a similar selection of rudists to those in the Brač marble of the Pučišća Fm on Brač (although according to Polšak and Mamužić, 1969 the Hvar deposits are of Cenozone VIa and those on Brač of Cenozone Vib), although on Hvar rudists are rarer. The deposits of Hvar, as described by Sladić-Trifunović (1980) from Pokonji Dol have yielded a rich orbitoid fauna. Preservation is poor, but determinations include:*Orbitoides media* (d'Archiac), *O. apiculata* Schlumberger, *Lepidorbitoides* sp., *Siderolites vidali* Douvillé, *Dissocladella savitriae* Pia and Ramo-Rao. Sladić-Trifunović is a strong advocate of a Maastrichtian age on the basis of the *Pironaea-Pseudopolyconites* rudist assemblage [although the foraminifera would suggest a more likely Late Campanian age].

Equivalent beds are also exposed at Fundinia, east of Titograd, Montenegro. This outcrop was mentioned in Milovanović in connection with a specimen of *Pironaea* which caused it to be assigned to the Early Maastrichtian and later Pejović (1969) was to name several more species from this locality, including *Fundinia* . The Montenegran beds also contain *K. tergestina* and the orbitoids *O. apiculata* and *O.media* (figured in Sladić-Trifunović, 1983) and are also probably equivalent to the lower part of the Brač Fm on Brač Island. A *Pironaea* considered equivalent (in its older growth stages) to *P. polystyla slavonica* has been found on the Pelješac Peninsula (Milovanović, 1960) and the outcrop was hence assigned to the Middle Maastrichtian.

The beds which overlie those of the Pučišća Fm on Brač island are those of the Brač Fm of Pejovič and Radoičić, 1987 and this is further divided into two foraminiferal zones. The older member consists of beds with *Raadshoovenia* and *Murciella* and the younger member of beds with *Rhapydionina liburnica, Laffiteina mengaudi* and "*Broeckinella arabica*". These correspond to similar zones used in the work of Fleury (1980, cit. Pejovič and Radoičić, 1987) in Greece. The Brač Formation is not dated specifically in this paper but it is generally assumed that the *Rhapydionina liburnica* beds are Upper Maastrichtian in age (*sensu* Fleury). However Pejovič and Radoičić do comment that: "A number of foraminiferal species considered to disappear before the Maastrichtian are found here even in beds with *Rhapydionina liburnica* and *Laffiteina mengaudi* (*Cuneolina, Montcharmontia apenninica compressa, Nummofallotia apula, Minouxia lobata, Tetraminouxia, Stensioina surrentina* and others). It is noteworthy that some of these species in similar series of Gavrovo-Tripoliza zone in Greece disappear much earlier.".

Summary and revision of dating

Pučišća Fm - Only two specimens were dated with Sr-isotopes from the Brač marble, one from E. Brač and the other from N. Brač. The specimens gave different answers, the former at Ca11, the latter at Ca48 which confirms hypotheses that the unit was deposited on a prograding ramp (Pejović, pers. comm., 1989). A date in the early-middle Campanian agrees with the views of Pejović & Radoičić (1987) who suggested this age based on the presence of *K. tergestina* in the coeval strata. This is further evidence for range of *Pironaea* and *Colveraia* in the Adriatic in early Campanian strata. **Ca10-?**

Brač Fm - The upper portion contains *Rhapydionina liburnica* which I now consider to be from the early-middle Maastrichtian in the Periadriatic (≈Ma25-Ma60) using the results from Dolenja Vas and this is supported by the continuing presence of those foraminifera which became extinct at lower levels in Greece. **Ma0?-Ma40**

2.2 Adriatic Platform

2.1a N.Italy (M. Jouf)

The uppermost parts of the sequence are best displayed on M. Jouf (fig.5/7). From Units 2 & 3 of M. Jouf come the foraminifera *Montcharmontia apenninica* (De Castro), *Cuneolina* aff. *pavonia parva* Henson, aff. *Stensioïna surrentina* Torre, aff. *Abrardia mosae* (Hofker) and *Tetraminouxia* aff. *gibbosa* Gendrot which all together suggest a most likely age of Campanian (Bilotte, pers. comm., 1989). Of the rudists, two specimens from the base of Unit 2 strongly resembled the *Vaccinites* aff.*giganteus* figured by Pleničar in the Coniacian-Santonian of M. Nanos, Yugoslavia . Most of the other rudists from Units 2 & 3 can not be constrained further than Senonian using evidence for their ranges in Yugoslavia (Senonian = Coniacian-Maastrichtian for most Yugoslavian workers). For example *Katzeria* from facies 2 (& 4) is recorded in the Senonian of Slovenia (Pleničar, 1973, 1974), *Bournonia excavata* from facies 3 in the Senonian of Croatia (Polšak & Mamužić, 1969) and *Pseudopolyconites* sp. 1 from facies 3 in the Dinarides mostly in the Maastrichtian but also as far down as the Coniacian (Sladić-Trifunović, 1983).

Unit 4 had a diverse assemblage of rudist genera such as *Pironaea, Pseudopolyconites, Sabinia, Joufia* and *Colveraia* which have all come to be regarded as Maastrichtian in Yugoslavia (Sladić-Trifunović, 1983). They co-occur with orbitoids *Orbitoides (O.??tissoti), Lepidorbitoides* and *Siderolites* (*S. gr. vidali*). Saint-Marc (1963) also records the species *Orbitoides media* d'Arch., *Simplorbites* sp., *Lepidorbitoides* sp. and *Siderolites calcitrapoides* Lmk from M. Jouf. Cousin (1963) records a unit of orbitoid limestones which overlies the Cretaceous rudist limestone on M. Pedroc and included the species: *Lepidorbitoides minor* Schlumb., *L. socialis* (Leym.), *Siderolites calcitrapoides* Lmk, and *Hellenocyclina beotica* Reichel.

M. Jouf, N. Italy

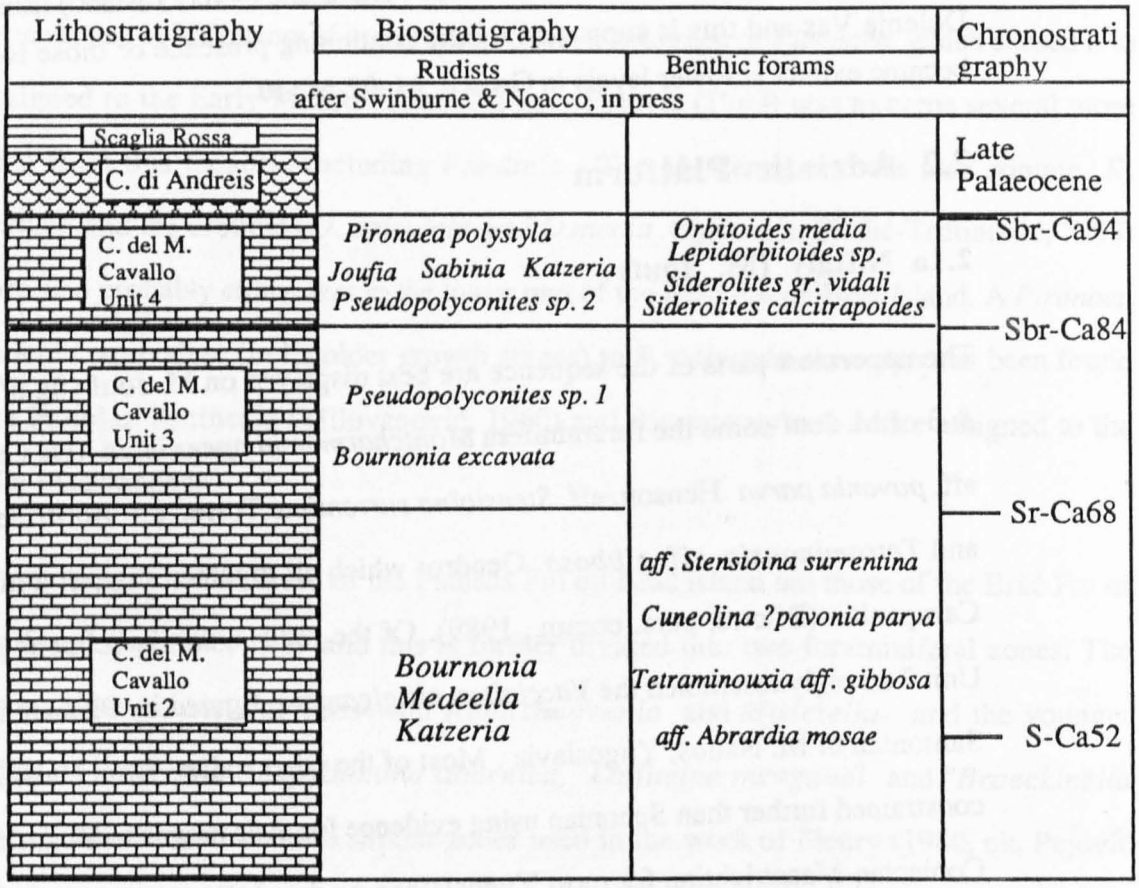


Figure 5/9

Summary of dating

Facies 2 - collection of smaller benthic foraminifera mostly regarded as Santonian - Campanian was dated precisely with the Sr-isotopes and the top was in the middle of the Campanian. **up to Ca68**

Facies 3 - with *Pseudopolyconites* with a mostly Maastrichtian reputation. Sr-isotope dates confirm the later part of the Campanian. **Ca68-Ca84**

Facies 4 - collection of so-called larger rudists such as *Joufia, Sabinia* and *Pironaea* with a predominantly Maastrichtian reputation and orbitoids including *S. calcitrapoides* known from the planktonic foraminiferal Maastrichtian. Here they are in beds correlated with the Boreal Late Campanian. **Ca84-Ca94**

2.3. Apulian Platform

2.3a Murges

The uppermost part of the **Calcari di Altamura**, as described by Laviano (1984) was attributed by her to the Late Campanian, or more probably Maastrichtian (fig. 5/10). This was due to the presence of the rudists *Joufia cf. reticulata* , *Sabinia cf. anienis* , *Mitrocaprina* sp., the benthic foraminifera *Goupillaudina, Orbitoides* and the planktonic foraminifera *Globotruncana* . Beds with *Joufia* were also found by other authors such as Vezzani (1968) (cit. Laviano, 1984) with a foraminiferal fauna including: *Dicyclina schlumbergeri* Munier-Chalmas, *Cuneolina pavonia parva* Henson, *Pseudolituonella reicheli* Marie, *Stensioina* sp. and in the upper levels *Accordiella conica* Farinaci, *Siderolites* sp. and *Murgiella lata* Luperto Sinni. Laviano also cites the work of Mastromatteo (1972) who reassigned some of Vezzani's Cenomanian outcrops as Late Senonian because of the presence of *Joufia* and a microfauna which included *A. conica* Farinacci, *Montcharmontia apenninica* (De Castro) and orbitoids belonging to the group of *O. media.*

Summary and revision of the ages

Calcari di Altamura - Given the ranges of these rudists is now known to be from the early Campanian - middle Maastrichtian and that most of the foraminifers are also from Early Campanian and Santonian strata I would tentatively revise these ages downwards. - **Ca60**

Murges, S. Italy

Lithostratigraphy	Biostratigraphy		Chronostratigraphy	
	Rudists	Benthic forams		
	after Laviano, 1983 & 84			this work
			Pliocene	
Calcari di Altamura	*Joufia reticulata* *Sabinia* cf. *anienis* *Mitrocaprina* sp.	*Orbitoides* gr. *media* *Dicyclina schlumbergeri* *Cuneolina pavonia parva* *Accordiella conica*	Maastrichtian - ? Late Campanian	br-Ca50?
	Hippurites nabresinensis		Early Senonian	

Figure 5/10

2.3b Gargano

Borgomano (1987 - cit. Borgomano & Philip, 1987) would refer the top of the *in situ* platform carbonates at Ostuni (the Altamura limestone) to the Santonian - Early Campanian (though in Borgomano & Philip, 1987 they do not say why). They would however prefer to place the slope deposits of the Caramanica Formation in the Late Senonian, ie. Upper Campanian-Maastrichtian (see fig. 5/11). This is both because of the orbitoids which co-occur with the rudists and because of the planktonic foraminifera in the pelagic deposits which interfinger with the talus (see fig. 5/12).

Summary and revision of the ages

Caramanica Fm - Using the planktonic foraminiferal ranges shown by Borgomano & Philip and taking into account that their C/M boundary is at ≈Ca86, the rudists probably do not go above Ma65. **? - Ma65**

2.3c Salento

In the shelf edge facies of the Poggiardo-Santa Cesarea Terme area many of the typical "Maastrichtian" rudists of Yugoslavia - *Joufia, Sabinia, Pseudopolycontites, Pironaea* - are found (fig. 5/13). Along with these rudists come the benthic foraminifera: *Raadshoovenia salentina* (Papetti & Tedeschi), *Cuneolina pavonia parva* Henson, *Cuneolina pavonia parva* Henson, *Dicyclina schlumbergeri* Munier-Chalmas, *Accordiella conica* Farinacci, *Montcharmontia apenninica* De Castro and *Orbitoides* cf. *media* D'Archiac. An important consideration in the adoption of the age Upper Campanian-Maastrichtian is *R. salentina* which is thought to have that age range.

In the inner shelf facies the occurrence of *Medeella zignana* (Pirona) signifies the Late Campanian. *Apricardia pachiniana* Sirna, which is known from Sicily in the Maastrichtian (Sirna, 1983, cit. Cestari & Sirna, 1987), in Salento is thought to be Late Campanian. The small benthic foraminifera *Rhapydionina liburnica* (Stache), which is present only in the inner shelf facies, is regarded by Cestari & Sirna as diagnostic for the Late Maastrichtian.

Summary and revision of ages

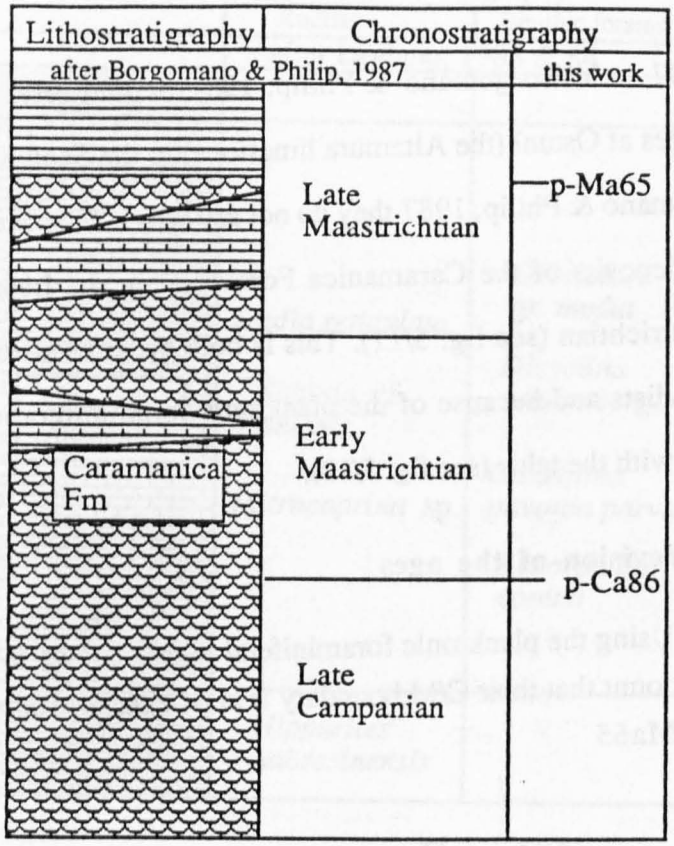


Figure 5/11

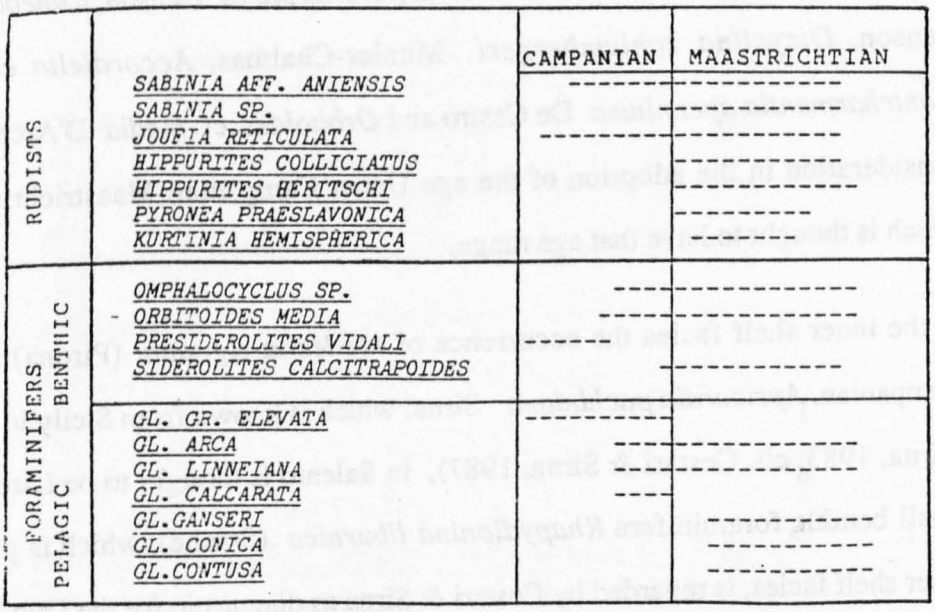


Fig. 4 - Biostratigraphy of the upper Senonian according to a detailed study of the Gargano and Murges series.

Figure 5/12. Detailed biostratigraphy of rudists and foraminifera at Gargano. From Borgomano & Philip, 1987.

Salento, S. Italy

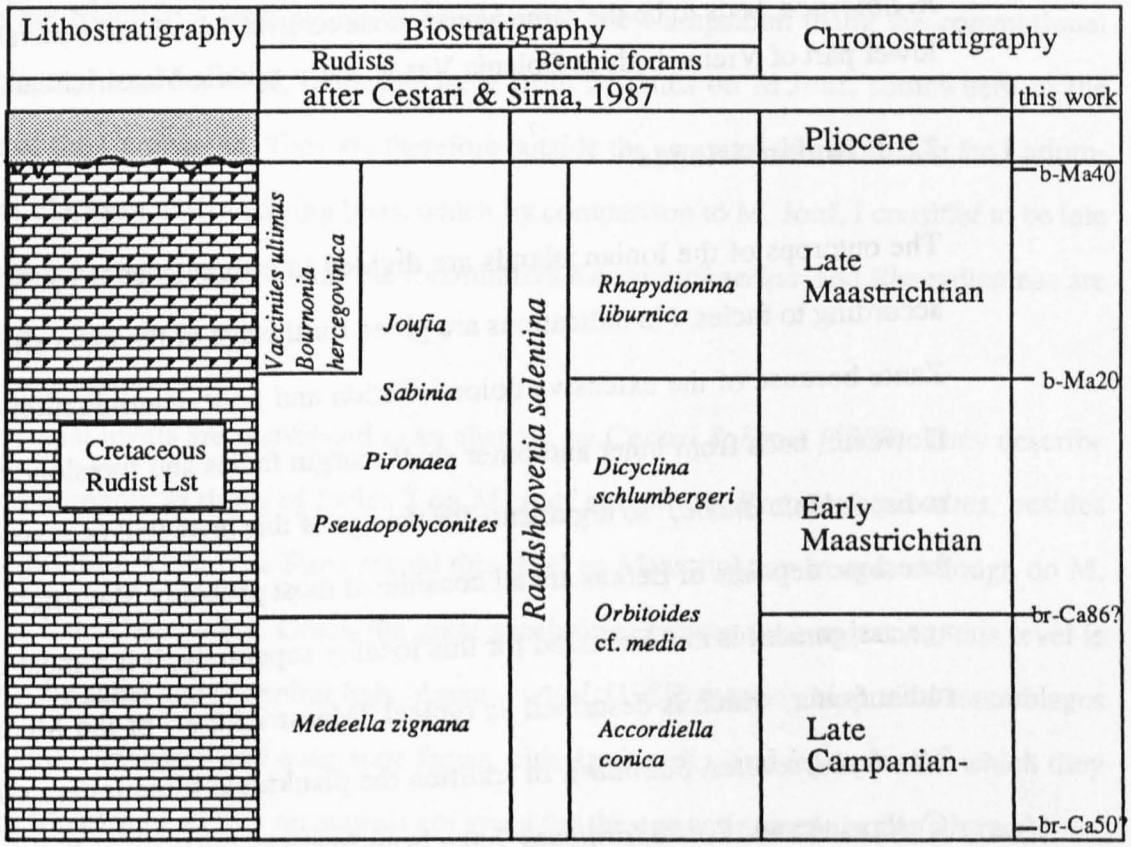


Figure 5/13

For the beds below those with *Rhapydionina liburnica* the foraminifera and rudists merely suggest early Campanian-middle Maastrichtian and most probably Campanian. I consider the *R. liburnica* beds to be the same age as those on Brač island and equivalent to the age of the lower part of Vreme beds at Dolenja Vas ie. early-middle Maastrichtian. **Ma20-Ma40**

2.3d Ionian islands

The outcrops of the Ionian islands are divided into three groups by Accordi *et al.* (1987), according to facies. No indications are given for the age of the inner shelf facies outcrop on Zante because of the extensive dolomitisation and poor determination of the rudist fauna. However, beds from inner and outer shelf margin facies and foreslope have all yielded the rudist *Sabinia anienis* so arguments for the age of this level will be considered together. The foreslope deposits of Lefkas are all considered most probably Maastrichtian and, though the age assignment is not discussed for this locality separately, it is almost certainly due to the rudist fauna, which is described as typical "Maastrichtian" of the Mediterranean (*Joufia, Pseudopolyconites, Sabinia*). In addition the planktonic foraminifera *Globotruncana arca* (Cushman) and *Rosita fornicata* have been found in (or between?) the rudist blocks. The outer shelf margin sediments of Harakti, Kephallinia are also considered Maastrichtian, but on the basis of levels of planktonic foraminifera (unspecified in Accordi *et al.*, 1987) intercalated in the sequence. Only a vague Santonian-Maastrichtian age is assigned to both outcrops of inner shelf margin facies. The rudist species are listed and it is noted that orbitoids are also found.

Summary and revision of ages

Most of the rudist bioherms are probably late Campanian but there is insufficient evidence to say more.

2.4 Central Italy

In the sequences mentioned by Mariotti (1982) from the Latium-Abruzzi Platform the last rudists are three *Vaccinites* species and then radiolitid bioherms with *Gorjanovicia-Durania* (+*Sabinia*) bioherms. The same is probably true for the Matese platforms although in the description of Accordi *et al,* 1982's the rudists are not described stratigraphically. However,

a similar collection of *Vaccinites* together with *Durania, Distefanella* and various nerineids are recorded. In the very similar sequences from the Adriatic and Apulian Platforms these genera are found at a level which is considered Late Campanian using the conventional biostratigraphic scheme or, more precisely from Sr-dates on M.Jouf, somewhere in the middle of the Campanian. They are therefore outside the scope of this work. On the Latium-Abruzzi Platform, the overlying beds, which by comparison to M. Jouf, I consider to be late Campanian-earliest Maastrichtian the foraminifera *Keramosphaerina* and Rhapydioninae are recorded.

Higher rudist levels are mentioned in an abstract by Cestari & Sirna (1988). They describe similar sediments to those of facies 3 on M. Jouf containing *Pseudopolyconites*, besides other radiolitids. Cestari & Sirna regard this level as Maastrichtian in age, although on M. Jouf it is Late Campanian. Given the great similarities between the sequence, this level is probably the same age in central Italy. Accordi *et al.* (1988) mention hippuritid assemblages with *Joufia, Pironaea* and a separate facies with *Apricardia* and *Radiolitella* which they consider Maastrichtian (but no reasons are given for the age assignment in this abstract).

Summary and revision of ages

Most of the *Joufia-Pironaea* rudist bioherms are probably late Campanian but there is insufficient evidence to say more.

3. North African Region

3.1 Southern Spain

Nicklès cited the occurrence of two ammonites: *Heteroceras (=Bostrychoceras) cf. polyplocum* (Roemer) and *Pachydiscus cf. oldhami* de Grossouvre at the top of what is now the Chaume Fm. According to Blaszkiewicz (1980) and Gallemi *et al.*, (1983 - both cit. Philip, 1985a) these beds are Late Campanian in age.

In the Bastida and Torrella Fms (fig. 5/14) rudists and larger foraminifera have been identified. Using the larger foraminifera to date the beds Philip (1985a) uses the following arguments: *O. media, cf. O. tissoti* and *S. vidali* (which come from the *Pironaea* unit) are

Quatretonda, S. Spain

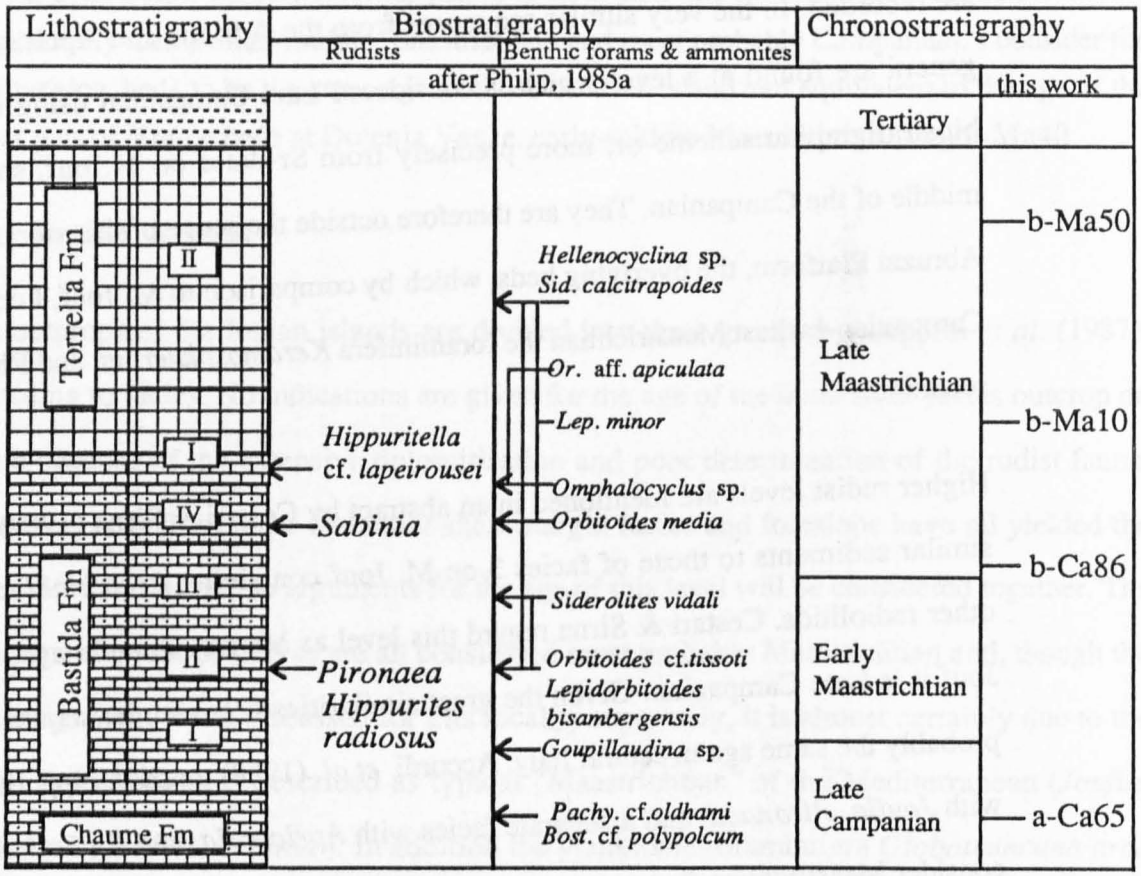


Figure 5/14

in favour of a Late Campanian age following Neumann (1972, 80 - cit. Philip, 1985a) or Early Maastrichtian *sensu* Bilotte, 1985. *L. bisambergensis* is, according to Van Gorsel (1975 - cit. Philip, 1985a) present in beds of Early Maastrichtian and earliest Late Maastrichtian age. Foraminifera from the top of unit III include *Lepidorbitoides minor* (Schlum.), primitive species of *Omphalocyclus* and cf. *Simplorbites gensacicus* (Leym.) which Philip supposed to be of Late Maastrichtian age *sensu* Van Gorsel, 1975 and Villain, 1977 (both cit. Philip, 1985a). In the Torrella Fm, also regarded by Philip as Late Maastrichtian in age, the fauna is similar but with the addition of *Siderolites* aff. *calcitrapoides* in the lower part (where the rudists are still found). In the upper part comes *Hellenocyclina* sp. [and this is Late Maastrichtian in the Pyrenees, according to Bilotte, 1985].

Philip also discusses the evidence for the age given by the rudists. [However it should be mentioned that there were only very few specimens and some determinations were made from single, often incomplete specimen (Pons, pers. comm., 1987)]. Philip mentions that *P. milovanovici* was then only known in the Late Maastrichtian, *P. polystyla* from the Middle Maastrichtian and *P. corrugata* from the Early Maastrichtian of Yugoslavia and Bulgaria. *Hippurites radiosus* from the 'Dordonian' of Aquitaine [regarded as Early Maastrichtian in Philip & Bilotte, 1985] and the Maastrichtian of the Pyrenees was also noted. This evidence, together with that of the *Lepidorbitoides* caused unit II to be given an Early Maastrichtian age (despite the argument based on the *Orbitoides*).

Summary and revision of ages

Top of Chame Fm - The ammonites are generally thought to be Late Campanian forms (≈Ca65-Ma0). **?-Ca70**

Bastida Fm - The orbitoid foraminifera *O. tissoti* and *S. vidali* are generally considered Campanian (≈Ca18-Ca86) elsewhere and I think that this holds true. **Ca70-Ca86**

Torrella Fm - *S. calcitrapoides* , *O. apiculata* , *L. minor* and *O. macroporus*, , can now be considered to range throughout the planktonic foraminiferal Maastrichtian (≈Ca86-Ma100). Their range in the French Pyrenees, (which probably influence this dating), where they are mostly late Maastrichtian forms (≈Ma60-Ma92), is quite atypical *Hellenocyclina beotica* from the top is probably from the middle of the Maastrichtian. **Ca86-Ma50**

3.2 Western Italy

The three *Sabinia* species which Parona named from Subiaco, *S. sublacensis*, *sinuata* and *anienis* (this has been misspelt as *aniensis* by subsequent authors) have been assumed to be Maastrichtian when they occur elsewhere as they are part of the typical *Joufia-Sabinia-Pironaea* fauna of central Tethys though I show them to be Campanian in many places.

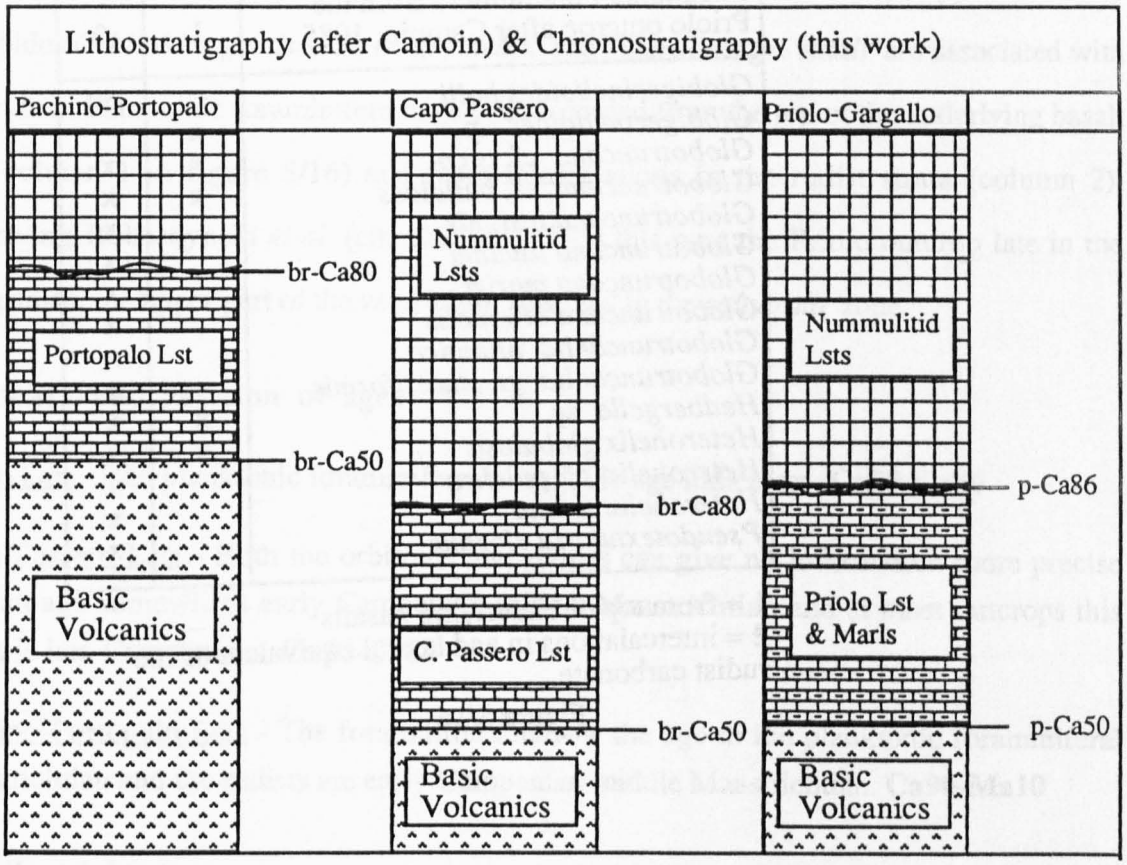
3.3 Sicily

The Sicilian outcrops are isolated from one another and were probably originally separate growths on the top of fresh volcanic rock. In considering their age therefore each must be treated separately (see fig. 5/15).

Outcrop in the Pachino-Portopalo region is thought to be Maastrichtian, probably Late Maastrichtian (Camoin *et al.*, 1983). The basis for this assertion is the presence of the hippuritid, *Hippurites cornucopiae* and its purported occurrence in Bosnia, Yugoslavia (Devidé-Nedela & Polšak, 1961, cit. Camoin *et al.*, 1983); the radiolitids *Joufia reticulata* and *Lapeirouseia cf. crateriformis* and their range in Bosnia (Sladić-Trifunović, 1972, cit. ibid.); and the larger benthic foraminifera *Simplorbitoides gensasicus* (Leymerie), *Lepidorbitoides socialis* (Leymerie), *Omphalocyclus macroporus* (Lamarck) and *Siderolites calcitrapoides* (Lamarck) [also *Orbitoides apiculata* according to Matteucci *et al.*, 1982] and the stratigraphic distribution according to Villain, 1977 (cit. ibid.).

The Island of Capo Passero outcrop is stratigraphically a few metres lower than that on the coast at Portopalo and is also thought to be slightly older (Early Maastrichtian according to Camoin, 1983) because of faunal differences. On Capo Passero larger benthic foraminifera are rare and only the genera *Orbitoides* and *Siderolites* can be determined. The rudist fauna is notably diverse with the *Joufia, Sabinia* and *Pseudopolyconites* which are so common on the Periadriatic platforms found together with rarer forms such as *Mitrocaprina* and *Neoradiolites* [which are better known in the Internal Dinarides and Balkans]. Camoin *et al.*, 1983 cite the occurrence of these species in the "partie moyenne" or "partie supérieure" of the Maastrichtian in Yugoslavia and in the Maastrichtian in general, of S. Italy.

Sicily



Lithostratigraphy	Biostratigraphy		Chrono-stratigraphy
	Foraminifera	Rudists	
after Camoin, 1983 & Camoin *et al.*, 1983 & 1985			
Portopalo Rudist Lst	*Lepidorbitoides socialis* *Omphalocyclus macroporus* *Siderolites calcitrapoides*	*Hippurites cornucopiae* *Joufia reticulata* *Lapeirouseia* aff. *crateriformis*	Late Maastrichtian
Capo Passero Rudist Lst	*Orbitoides* sp. *Siderolites* sp.	*Sabinia anienis* *Joufia reticulata* *Vaccinites ultimus*	Early Maastrichtian
Priolo-Gargallo Rudist Lst	zone of *Globotruncana elevata*	*Joufia reticulata* *Sabinia anienis*	Late Campanian

Figure 5/15

Planktonic Foraminifera from the Priolo outcrop after Camoin, 1985	1	2
Globigerinelloides bolli		x
Globigerinelloides sp.	x	
Globotruncana cf. *arca*	x	x
Globotruncana cf. *bulloides*	x	x
Globotruncana insignis		x
Globotruncana lineiani		x
Globotruncana mariei		x
Globotruncana orientalis		x
Globotruncanita atlantica		x
Globotruncanita gr. *stuartiformis*		x
Hedbergella sp.	x	x
Heterohelix globulosa	x	x
Heterohelix cf. *pulchra*		x
Heterohelix striata		x
Pseudotextularia elegans		x

1 = from top of underlying basalts
2 = intercalations in and lateral equivalent of the rudist carbonate

Figure 5/16

The Priolo outcrop has yielded *Sabinia* and *Joufia* as well as rare hippuritids. The orbitoides *Orbitoides gr. tissoti* , *O. gr. media* and *Siderolites gr. vidali* are associated with the rudists. Planktonic foraminifera have been recorded from the top of the underlying basalt (see column 1 in figure 5/16) and from intercalations in the rudist strata (column 2). Following Robaszynski *et al.* (cit. Camoin, 1985) this puts the Priolo outcrop late in the Campanian, the upper part of the *ventricosa* zone and in the *calcarata* zone.

Summary and revision of ages

Priolo Lsts - The planktonic foraminifera are reliable age indicators. **Ca50-Ca86**

Capo Passero Lsts - Both the orbitoids and rudists can give no information more precise than an age somewhere early Campanian-middle Maastrichtian and at most outcrops this fauna is late Campanian. **Ca50-Ca80**

Pachino-Portopalo Lsts - The foraminifera narrow the age to the planktonic foraminiferal Maastrichtian and the rudists are early Campanian-middle Maastrichtian. **Ca90-Ma10**

3.4 Tunisia

The age of the bioconstruction at Jebel Serraguia (fig. 5/17) is constrained by planktonic foraminifera in underlying and overlying beds. The underlying beds yielded *Globotruncana lapparenti* Brotzen and *Gl. coronata* Bolli, forms which were attributed by Bernet-Rollande & Philip (1981) to the Santonian. Immediately overlying the limestone is a chalk unit with *Globotruncana elevata stuartiformis* Dalbiez as well as the benthic foraminifera *Arnaudiella* and *Orbitoides tissoti* Schlumberger which are regarded as middle Campanian. This age fits well with the evidence from the top of the chalk unit which yielded *Globotruncana* cf. *bulloides* Vogler, *Gl. gagnebini* Tiler, *Clavulinoides trilatera* (Cushman), an assemblage apparently indicating an age in the interval latest Campanian to the middle Maastrichtian. Direct evidence for the age of the rudist unit cited in Bernet-Rollande & Philip, 1981 is the occurrence of *Sabinia* in the Campanian-Maastrichtian of S. Italy, Yugoslavia and Turkey.

At the Jebel El Kébar outcrop (fig. 5/17), the upper part of the underlying formation, the Aleg Fm has yielded planktonic foraminifera which enabled Khessibi (1978 - cit. Negra &

Tunisia

i) Jebel Serraguia

Lithostratigraphy	Biostratigraphy: Foraminifera	Biostratigraphy: Rudists	Chronostratigraphy	Chronostratigraphy: this work
	after Bernet-Rollande & Philip, 1981			
			Quaternary	
Chalk II	*Gl.* cf.*bulloides* *Gl. gagnebini*		Latest Campanian-Middle Maastrichtian	
Chalk I	*Orbitoides tissoti* *Gl. elevata stuartiformis*		Middle Campanian	p-Ca78
Jebel Serraguia Rudist Reef		*Sabinia* *Joufia* Hippuritids	Campanian	p-Ca50
Marls & Lsts	*Gl. lapparenti* *Gl. coronata*		Santonian	p-Sa

ii) Jebel Kébar

Lithostratigraphy	Biostratigraphy: Plank. forams	Biostratigraphy: Rudists/benth. forams	Chronostratigraphy	Chronostratigraphy: this work
	after Philip & Negra, 1986			
Belghia & Segui Fms			Mio-Pliocene	
			Maastrichtian	
Merfeg Fm: Rudist Lst III	*Rosita fornicata*	*Vac. ultimus* *Vac. braciensis* *Rajka spinosa*	Late Campanian	p-Ca78
Merfeg Fm: Rudist Lst II	*Gl.* cf.*arca*	*Pssid. vidali* *O.tissoti*		
Merfeg Fm	*Gl.* cf.*bulloides* *Gl.* cf. *"tricarinata"*	*Pir.* cf.*timacensis* *Pir.* cf.*corrugata* *Vac. braciensis*		
Merfeg Fm: Rudist Lst I	*Gl.* gr. *stuarti-stuartiformis*	*Htes colliciatus*		p-Ca40
Aleg Fm			Early Campanian	

Figure 5/17

Philip, 1987) to call this Early Campanian. Negra & Philip divide the Merfeg Fm into two cenozones based on the rudists. The association of rudists from the first unit (which makes up the first cenozone) is characterised by *Hippurites colliciatus, Vaccinites braciensis, Pironaea cf. corrugata* and *P. cf. timacensis*. Negra & Philip use this as evidence for a Late Campanian-Early Maastrichtian age by comparisons with Yugoslavian and Italian authors (although *V. braciensis*, synonymised by Sladić-Trifunović (cit. Negra & Philip, 1987) with *V. oppeli santoniensis* is also known in the Early Campanian and Santonian (cit. ibid.). The second cenozone which covers the second and third units has *Vaccinites ultimus, V. braciensis* and *Rajka spinosa*, (species of similar purported ranges, though *V. ultimus* is particularly abundant in the Maastrichtian of Yugoslavia (Milovanović, 1984; Sladić-Trifunović, 1978; both cit. Philip & Negra, 1987)) and the larger foraminifera *Pseudosiderolites vidali* and *Orbitoides tissoti*. Philip & Negra cite the views of M. Neumann and H. Bismuth who consider these two foraminiferal species diagnostic for a late Campanian age.

The marly intercalations between the rudist units yielded the following fauna of planktonic foraminifera and coccoliths: *Rosita cf. fornicata* (Plummer), *Globotruncana cf. arca* (Cushman), *Gl. cf. bulloides* Vogler, *Gl. cf. "tricarinata"* (Quereau) and *Gl. gr. stuarti-stuartiformis* . There was no difference in the assemblage between the different intercalations. An age for the Merfeg Fm in the range Campanian-Early Maastrichtian was concluded.

Summary of ages

Jebel Serraguia Rudist Lst - Planktonic foraminifera above and below the reef constrain its age to early Campanian. **Ca0-Ca50**

Jebel Kébal Rudist Lst - Intercalations of planktonic foraminifera constrain the age to middle-late Campanian. **Ca40-Ca78**

4. Balkan-Eastern Alpine Region

4.1 Inner Dinarides: Western Serbia & Southern Serbia & Bosnia (Dragačevo, Gučevo, Lisa, Fruška Gora, Kozluk)

Internal Dinarides

Lithostratigraphy	Biostratigraphy		Chronostratigraphy	
	Rudists	Benthic Forams		
after Milovanović, 1960		& Sladić-Trifunović, 1972		this work
Flysch			Tertiary	
	Pironaea fruscagorensis *Hippuritella cornucopiae* *Hippuritella Lapeirousei* *Joufia reticulata*	*Orbitoides media*	Late Maastrichtian	pb-Ma50
Cretaceous rudist lst	*Pironaea polystyla slavonica* *Lapeirouseia*	*Omphalocyclus macroporus* *Siderolites calcitrapoides* *Loftusia occidentalis*	Middle Maastrichtian	br-Ca80
	Vaccinites oppeli		Campanian	

Benthic foraminifera from the Inner Dinarides cited in Polšak, 1965, Sladić-Trifunović, 1972 & 1983	1	2	3	4	5	6
Hellenocyclina beotica	x					
Lepidorbitoides cf. *bisambergensis*	x					
Lepidorbitoides cf. *pustulata*	x					
Lepidorbitoides socialis	x		x			
Lepidorbitoides sp.				x		
Omphalocyclus macroporus	x	x	x		x	
Orbitoides apiculata	x		x			x
Orbitoides cf. *disculus disculus*	x					
Orbitoides cf. *gensacicus*	x		x			
Orbitoides media	x	x	x	x	x	x
Siderolites calcitrapoides	x	x	x	x	x	
Siderolites vidali	x					
Miscellanea miscella	x					
Nummofallotia sp.	x					
Pseudotextularia varians	x					
Globotruncana arca	x					
Globotruncana contusa	x					
Globotruncana conica	x					
Globotruncana cretacea	x					
Globotruncana stuarti	x					

1 = Kozluk, NE Bosnia
2 = Bešpelj, nr Jajce, Bosnia
3 = Čerevićki potok, Fruška Gora
4 = Dragačevo, W. Serbia
5 = Vratonjic Krš, Lisa, W. Serbia
6 = Fundinia, nr Titograd, Montenegro

Figure 5/18

The rudists beds of Leposavić, southern Serbia are considered equivalent to the uppermost of the Gosau hippuritid levels characterised by *Hippurites* [now *Vaccinites*]*oppeli* (Milovanović, 1960) and thus Campanian in age, outside the scope of this discussion. At the localities of Dragačevo, Gučevo and Lisa in Western Serbia and those in the Fruška Gora area, (fig. 5/4.1a) the same *H. oppeli* level could be found and the overlying beds are the only ones which have been suggested to be of Maastrichtian age. They contain a species of *Pironaea* , *P. polystyla slavonica* as well as large specimens of *Lapeirousia*.. *P. p. slavonica* was the middle form in Milovanović's evolutionary scheme of *Pironaea*, the evolutionary succession developed for the rocks of eastern Serbia (see under that section). On that basis this rudist level in the Internal Dinarides was considered middle Maastrichtian (Milovanović, 1960). This was despite the absence of either the under- or overlying *Pironaea* level.

According to Milovanović (1960) several localities with *Pironaea polystyla slavonica* have also yielded the large benthic foraminifera *Loftusia* (*L. morgani* Douvillé, *L. occidentalis L. elongata* Cox,) which is supposedly Maastrichtian in age and the first two at least are found in the Internal Dinarides. *Loftusia* is also found in eastern Serbia (Milovanović, 1932), but there is no mention of it in any of the pure carbonate sequences of the External Dinarides. [The absence of this form may be palaeobiogeographic or due to facies. The latter is a possibility as *Loftusia* in Arabia was found only in association with marly rather than pure carbonate lithologies - P.W. Skelton, pers. comm.]

Following new finds of the genus *Pironaea* the upper level of Late Maastrichtian age was thought to have been located in the Internal Dinarides at Fruška Gora and at Kozluk. The orbitoids from various localities listed in Sladić-Trifunović, 1972 are listed in figure 5/18 and those from Kozluk, in particular are considered by that author as typical for the Late Maastrichtian (*sensu* Neumann, 1958 cit. Sladić-Trifunović, 1972). However some of the rudists such as *Hippurites cornucopiae* and *Hippuritella lapeirousei* are found at other localities to accompany *P. polystyla slavonica* in the middle Maastrichtian. Sladić-Trifunović therefore could not decide between a Middle or Late Maastrichtian age for these beds. Polšak (1965) described *Joufia* from the locality of Bešpelj in Bosnia where

planktonic foraminifera have been found (listed in figure 5/18) and the locality is assigned a middle Maastrichtian age.

Summary and revision of ages

The rudists give no more precision than an estimate of early Campanian-middle Maastrichtian for the so-called "Maastrichtian" beds. The foraminifera indicate only an equivalence to the planktonic foraminiferal Maastrichtian. However the presence of *H. beotica* at Kozluk suggests a level in the middle Maastrichtian for some of the uppermost beds. **?-Ma50**

4.2 Eastern Serbia & Western Bulgaria

4.2a Eastern Serbia

Biostratigraphic schemes from studies of the rudist sequences of eastern Serbia have had a profound effect on the subsequent dating of the Mediterranean deposits. It was from the outcrops at Bačevica that Milovanović recognised Maastrichtian strata, which he divided into 3 biozones of lower, middle and upper Maastrichtian strata, (figure 5/19) [presumed by him and later authors to be of early, middle and late Maastrichtian age] according to his (supposedly) evolutionary scheme of the genus *Pironaea*. The middle level could also be recognised in the Internal and External Dinarides and caused it to be considered middle Maastrichtian. Although subsequent work has shed doubt upon these conclusions (see later) it is worthwhile exploring the development of Milovanović's ideas as to this dating.

In the first record of the Bačevica localites Milovanović, in 1932, actually called these beds Campanian, an opinion which he was to change by 1934 (Milovanović, 1934a) when he attributed the upper level to the Maastrichtian. The reason for the change seems to be that he had been puzzled by the observation that in eastern Serbia the rudists seemed to have greater stratigraphic ranges that those attributed to them in France by Toucas. To solve this apparent paradox he concluded that some rudists had been reworked from lower strata and as evidence he cited (Milovanović, 1934b) the rounding and abrading of rudists from upper levels which were better preserved when they had appeared in lower levels.

Eastern Serbia

Lithostratigraphy	Biostratigraphy		Chronostratigraphy	
	Rudists	Benthic Forams		
after Milovanović 1960				this work
Cretaceous rudist lst	*Pironaea polystyla milovanovici* *P. p. bacevicensis*	*Loftusia morgani*	Late Maastrichtian	br-Ma28?
	Pironaea polystyla slavonica *Pseudopolyconites* sp. div. *Lapeirouseia*		Middle Maastrichtian	
	Pironaea corrugata		Early Maastrichtian	
	Vaccinites oppeli		Campanian	r-Ca30

Figure 5/19

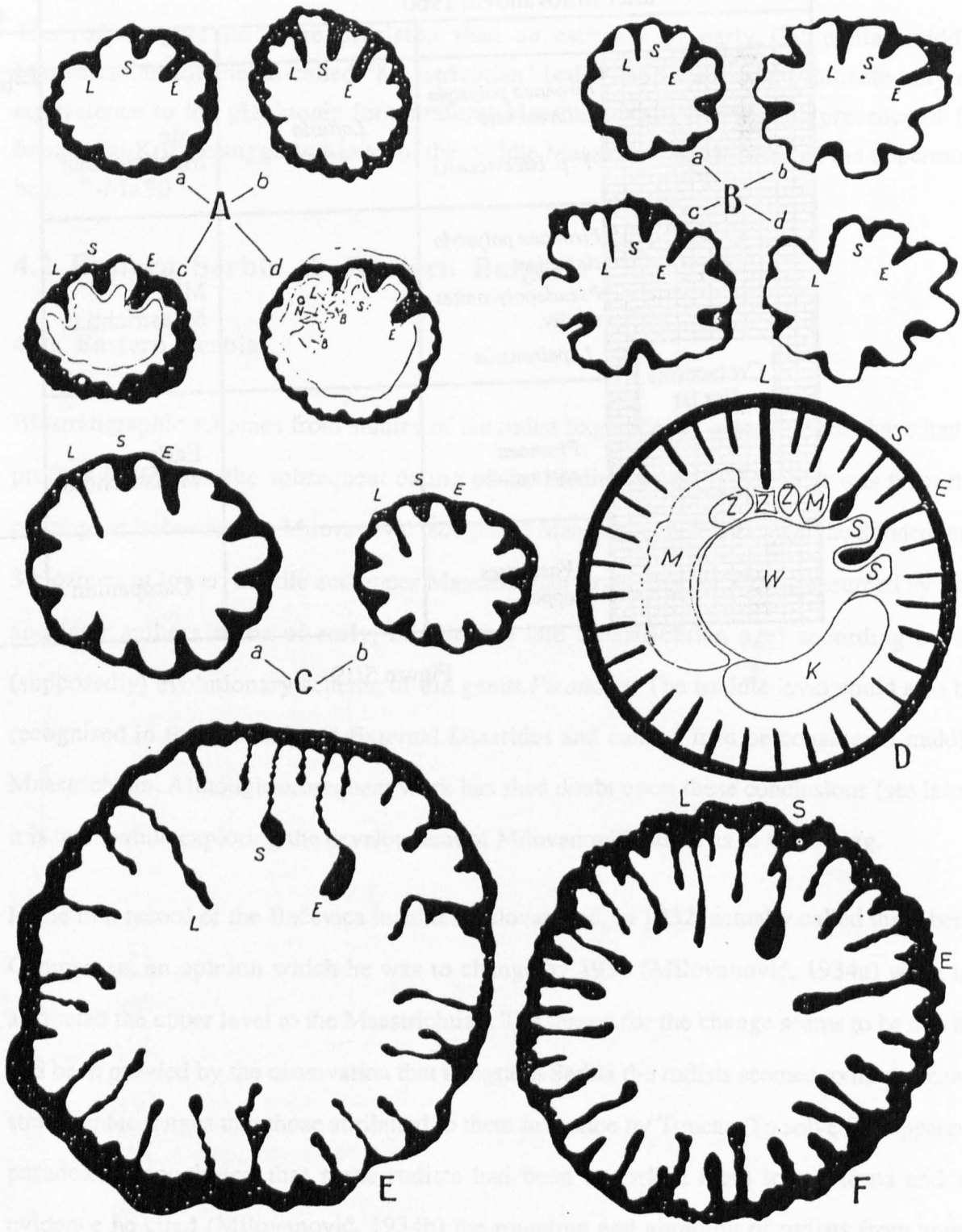


Figure 5/20. Diagram of cross sections of *Pironaea* specimens showing the "species" used in Milovanovic's evolutionary scheme of this genus.
A) *Vaccinites loftusi* , Campanian
B) *Pironaea corrugata* , lower Maastrichtian
C) *Pironaea polystyla slavonica*, middle Maastrichtian
D) & E) *Pironaea polystyla milovanovici*, upper Maastrichtian
F) *Pironaea polystyla machnitschi*

In 1934b he presented his zonal scheme for the uppermost beds of the Vrbovac "reef" based on the genus *Pironaea*. The zones consist of *Pironaea* species which show progressive complication in their structure, notably of the infoldings of the outer shell wall, and they were thought to represent an evolutionary succession. The scheme of 1934b is essentially the same as presented in Milovanović, 1960 from which figure 5/20 is taken, although by then the age ranges of the zones had been simplified to lower, middle and upper Maastrichtian, and a few new subspecies of *Pironaea* created.

Zone I is characterised by *P. corrugata* (Woodward) (supposedly closely related to the ancestral form of *Vaccinites loftusi*) and corresponded to the early Maastrichtian and latest Campanian (Milovanović, 1934b). Zone II with *P. polystyla slavonica* (Hilber) "probably" corresponded to the middle Maastrichtan and contained that species together with *Hippurites lapeirousei* Goldfuss, *Pseudopolyconites serbicus* Milovanović, *P.parvus* Milovanović and *P. ovalis* Milovanović. Zone III of *Pironaea polystyla* (Pirona) comprised the late Maastrichtian and contained the largest forms of that species as well as *Vaccinites ultimus* Milovanović and *Neoradiolites orientalis* Milovanović (which is probably a *nomen nudum* as I can not find a description of this form). [By 1960 Milovanović's new subspecies *P. p. bacevicensis* and *P. p. milovanovici* had come to signify the upper zone.] Zone I rested on beds with the hippuritid *Vaccinites oppeli* and this was correlated with the fourth and last level of the Gosau beds of the eastern Alps, regarded by Milovanović (1960) as Campanian in age.

Following that scheme, Milovanović (1935b) elaborated on his views of the delineation of zones and mixing of forms. He noted that the Campanian/Maastrichtian boundary could not be placed precisely because the beds were massive and there were no sudden biostratigraphic changes. Although the level of *P. corrugata* (the lowest zone, which by then he regarded as early Maastrichtian) seemed to contain Campanian species, in places they contained a pure Maastrichtian fauna. The middle section was the thickest part of the Maastrichtian with many large forms. Some beds were monogeneric or even monospecific with only *Pseudopolyconites* , *Lapeirousia* , or *Pironaea polystyla slavonica*. In contrast to the lower

biozone, the middle was clearly delimited biostratigraphically by the appearance of the new genera *Pseudopolyconites* and *Yvania* (later to be called *Yvaniella* of which only one bizzare specimen has ever been found). The upper level was similar to the middle and in this rudists from other levels were by no means rare but were probably mostly not autochthonous (Milovanović, 1935b).

Milovanović in general perpetuated the strict division into early, middle and late Maastrichtian, and this has been followed by Sladić-Trifunović. In later years there have again been slight modifications. In Milovanović & Grubić, 1972 for example it was thought that the "Gosau beds" stopped in the Early Campanian and therefore likely that the *Pironaea* beds might start in the late Campanian. How far upwards they extended was not sufficiently determined. In Sladić-Trifunović, 1983 a range chart shows that, although there are "upper Maastrichtian" species they do not neccessarily range to the top of the Maastrichtian.

How long it took for the "Vrbovac reef" to be deposited is far from clear. Indeed it is quite possible that the succession is ecophenotypic. As the bioherm grew to reach the water surface conditions became more suitable for rapid growth and larger individuals resulted. There may well be some reworking of "older" forms under these conditions because there has not been much time for them to be buried out of reach of wave action.

That the different "species" of *Pironaea* are invalid has been demonstrated by Pons & Vicens (presentation at the First International Conference on Rudists held in Belgrade Yugoslavia, October 1988) because the less complicated development can be found in the younger growth stages of specimens of the supposedly evolved forms (ie. the variation can be ontogenetic). At Bačevica it is noted that the most evolved forms are also the largest. Furthermore, at several localities (Quatretonda, Spain, Philip, 1985a; Oman Mountains, Skelton *et al.*, 1990, Tuz Golu, Turkey, Skelton, pers. comm.) individuals from all three biozones have been found in the same bed.

It also seems unreasonable to me (with the benefit of an extra half century of literature on the subject) for Milovanović to have expected rudists in eastern Serbia to have the same ranges as those in France. Fortunately there are some other fossils from these beds which can be

used as independent age indicators. Milovanović (1932) mentions the belemnite *Belemnitella mucronata* which, if this is a correct diagnosis, would be indicative of the Upper Campanian in northern Europe. However, it is difficult to understand its position relative to the rudist zonation. From a level below that of *B. mucronata* orbitoids are mentioned but unspecified. Finally the larger foraminifera *Loftusia morgani* Douvillé is recorded in the topmost "upper Maastrichtian" rudist level.

Summary and revision of ages

The ages of these beds can be revised using comparisons to the outcrop of similar strata in Bulgaria where I have dated them. *V. loftusi* is abundant at Yaroslavtzi in Bulgaria in beds of middle Campanian age. In eastern Serbia the *V. loftusi* beds are overlain by those with *Pironaea* . However, *Pironaea* in Bulgaria is found in strata which are both older (early Campanian) and younger (early Maastrichtian) than those with *V. loftusi*.. There is therefore no conclusive evidence for the upper age of the eastern Serbia apart from *Loftusia* which is from beds equivalent to the planktonic foraminiferal Maastrichtian. I doubt that the sequence extends past the early Maastrichtian. **-Ma28**

4.2b Bulgaria

Pamouktchiev's dating of these outcrops was based to a large extent on the rudist fauna and on comparisons with that of eastern Serbia as described and dated by his erstwhile professor, Milovanović. A few specimens of ammonites and some orbitoids are also cited. The Bulgarian outcrops are part of the same palaeobiogeographic province as the outcrops in eastern Serbia and the sediments and their rudist fauna are very similar. Therefore much of the revision of dating of the eastern Serbian outcrops is also applicable to the Bulgarian (and *vice versa*). From Bulgaria there is also new evidence for the age of the beds in terms of more benthic foraminifera and Sr-isotope results (see figure 4/21).

The first rudist to be recovered from Garlo was *Vaccinites ultimus* (Milovanović) (Pamouktchiev, 1962), from the lowermost limestone lens which was already regarded as middle Maastrichtian (probably following earlier work at nearby outcrops by Tzankov). Garlo was correlated with the Yambol locality on lithological grounds because both localities directly overlie lavas. The upper limestone lens at Garlo is not mentioned until 1979a. It

Bulgaria

i) Breznik

Lithostratigraphy	Biostratigraphy		Chronostratigraphy	
	Rudists	Benthic Forams		
after Pamouktchiev, 1962, 66, 77, 79a		this work	after Pamouktchiev	this work
Plattenkalk			Palaeogene	
Yaroslavtzi radiolitid beds	*Vaccinites loftusi* *Hippurites heritschi* *Mitrocaprina bulgarica*	*Orbitoides tissoti*	Early Maastrichtian	Sbr-Ca60 Sbr-Ca40
Fault?				
Garlo *Pironaea* beds	*Pironaea milovanovici*		Late Maastrichtian	b-Ma5
	Pironaea polystyla garlensis *Vaccinites ultiuus* *Lapeirouseia jouanetti*	*Siderolites* gr. *vidali*	Middle Maastrichtian	Sb-Ca32
Volcanics				

ii) Yambol

Lithostratigraphy	Biostratigraphy		Chronostratigraphy	
	Rudists	Benthic Forams		
after Pamouktchiev, 1977		this work	after Pamouktchiev	this work
Yambol coral/rudist lsts	*Pironaea slavonica*	*Orbitoides apiculata* *Lepidorbitoides socialis* *Siderolites calcitapoides*	Late Maastrichtian	Sb-Ca92-Ma15
Volcanics				

Figure 5/21

seems to have been given the age of upper Maastrichtian, because it is stratigraphically above the lens dated as middle Maastrichtian, and because it contains an "advanced" species of *Pironaea, P. bacevicensis* (Milovanović) which was described from the upper Maastrichtian of eastern Serbia (Milovanović, 1960). The outcrops from Yaroslavtzi were dated as lower Maastrichtian (Pamouktchiev, 1962).

In 1977 Pamouktchiev mentioned four ammonites from the "middle Maastrichtian" of Garlo and Yambol which gave further evidence for the age. These are: *Pseudokossmaticeras brandti* (Redtenbacher), *Diplomoceras cylindraceus* (Defrance), *Pachydiscus gollevillensis* (d'Orbigny) and *Pachydiscus neubergicus* (Hauer). The first of these, *P. brandti* is undoubtedly a specimen from the Garlo locality according to Pamouktchiev (1962 - in the Bulgarian text). I presume that the other three come from Yambol as there is no mention of any of the other three in any other work apart from this, which is also the only work to mention the Yambol outcrops. From Yaroslavtzi Pamouktchiev, 1964 mentions the ammonite *"Pseudocossmaticeras aturicus* Seuness de zone à *Bostrychoceras polyplocum* Roemer" and Pamouktchiev, 1966 the orbitoids: *Orbitella* (i.e.*Orbitoides*) *media* (Arch.) and *Orbitoides apiculata* (Schlumberger) but these are not figured.

As regards the evidence for the age of the beds based on the rudist biostratigraphy, firstly most of the rudists cited by Pamouktchiev as typical of Milovanović's Maastrichtian (*Hlla. variabilis, Htes maestrei, V. loftusi, V. sulcatus*) are in fact Campanian in France, (a feature noted by Milovanovic and attributed to reworking) but there is no evidence for drastic reworking in Bulgaria. Secondly, following the discrediting of the *Pironaea* biostratigraphic scheme there is no evidence from this source for the upper age limit of the beds. In fact the most it would be reasonable to conclude from the rudist biostratigraphy would be, in my opinion is that the beds are probably Campanian-Maastrichtian in age.

A better dating of the beds could be obtained by the ammonites. Unfortunately I have not seen the cited ammonites and as there are no photographs in the rudist papers I cannot assess the validity of occurrence of the quoted species. If the determinations are correct then this would have the following consequences in terms of the age (W.J. Kennedy, pers. comm.).

The ammonites from Garlo, *Pseudokossmaticeras brandti* is known as a Maastrichtian species. Of the three from Yambol, *P. gollevillensis* is an exclusively Upper Maastrichtian species, found in the *junior* zone and possibly just into the *casimirovensis* zone; *P. neubergicus* is mainly a Lower Maastrichtian species and it occurs in stata of the *B. lanceolata* zone *(sensu lato)* at the base of the Boreal Maastrichtian (where the type section is situated), certainly in the *pseudobtusa* zone (*sensu* Schulz, 1979) and probably ranges into the *junior* zone at the base of the Upper Maastrichtian. From Yaroslavtzi *Pseudokossmaticeras aturicus* Seuness is a junior synonym of the Maastrichtian species *P. brandti* Redtenbacher but the zone of *Bostrychoceras polyplocum* in which it is supposed to occur is Upper Campanian.

In 1989 the following orbitoids were collected from all three outcrops and identified by Michel Bilotte with the following results: *Pseudosiderolites vidali* was found at Garlo, at the base of the sequence, just above the volcanic levels. The main part of the Yaroslavtzi outcrop yielded a monospecific assemblage of *Orbitoides* aff.*tissoti* Schlumberger. This species is essentially Campanian in the Pyrenees but can appear at the top of the Santonian and range into the Lower Maastrichtian (Bilotte, pers. comm., 1989). The cited specimens of *Orbitoides media* and *Orbitoides apiculata,* (figured in "Les fossiles de Bulgarie") are, according to Bilotte, wrongly diagnosed and both are *O. tissoti*.. The Yambol outcrop yielded an extrememly diverse and bio-stratigraphically useful fauna of: *Orbitoides apiculata,* (Schlumberger) *Lepidorbitoides* aff. *socialis* (Leymerie), *Siderolites* aff. *denticulatus* Douvillé, *Siderolites calcitrapoides* Lamarck and *Clypeorbis mamillata* , all forms found in the planktonic foraminiferal Maastrichtian.

Summary of dating

Yaroslavtzi radiolitid beds - Rudists are early Campanian-middle Maastrichtian. Foraminifera are Campanian. The ammonite is Late Campanian. Sr dates are precise in *O. tissoti* beds at Ca52. Samples from the main hippuritid & radiolitid level have probably been affected by diagenesis and results lower than they should otherwise have been. **Ca40-Ca60**

Garlo *Pironaea* beds - The lower lenses had Campanian foraminifera. The one Maastrichtian ammonite may come from the top of the succession. Sr-dates at the base were in the lower Campanian with Ca12 for the lowermost lens and a precise Ca32 for the second lens.

However the sequence probably extends upwards to around the Campanian/Maastrichtian boundary. **Ca32-Ma5**

Yambol - The foraminifera are from the planktonic foraminiferal Maastrichtian. Unsubstantiated ammonite records may indicate a level in the Boreal Upper Maastrichtian. Sr-isotope results gave an age of Ma8 thought there is a slight possiblity that samples had altered slightly to lower $^{87}Sr/^{86}Sr$ values. **Ma5-Ma10**

4.3 Romania

Rudists thought to be from the Campanian and Maastrichtian are found in three sedimentary basins in the northern Apuseni Mountains of Romania: the Rosia, Borod and Remeti Basins (see fig. 3/24 taken from Lupu, 1984 for the stratigraphy of the section and ranges of the rudist species). In the Rosia Basin the upper one of three levels, which contains various hippuritids and radiolitids is regarded as Campanian in age. In the Borod Basin three rudist horizons are recognised and the middle horizon contains a diverse assemblage of radiolitids and hippurids regarded as Campanian. The upper horizon contains the rudist genera *Joufia, Colveraia* and *Sabinia* and also the orbitoids: *Clypeorbis mamillata* (Schlum.), *Lepidorbitoides minor* (Schlum.) *Simplorbites gensacicus* (Leym.) and *Siderolites* sp which are species known to be from the Late Campanian-Early Maastrichtian. The equivalent of this rudist level is also found in the limestone beds at the top of the sequence in the Remeti basin where a species of *Pseudopolyconites, P. milovanovici* Lupu is found. By comparison to the Yugoslavian literature, this is considered characteristic for Early Maastrichtian strata.

Summary of ages

There is insufficient evidence to constrain further the *Joufia-Colveraia* and *Pseudopolyconites* beds other than lower part of the planktonic foraminiferal Maastrichtian.

4.4 Austria, Hungary & Czechoslovakia

Many of the East European workers have drawn comparisons between their deposits and the so-called Gosau beds of Austria. According to most recent authors in general these do not go above Santonian (Herm *et al.*, 1979, cit. Lupu & Lupu, 1981 & Höfling, 1988).

However, Lupu 1977 (cit. Lupu & Lupu, 1981) reported an isolated specimen of *Joufia* from Wittersdorf in Carinthia which she regards as evidence for Maastrichtian strata. Milovanović (1960) distinguished 3 rudist levels in the Gosau beds with the last, characterised by *Hippurites oppeli* and seen as Campanian in age. Pamouktchiev (1970) also published a paper on the Gosau beds (though he was unable to visit the outcrop) but regarded some rudists as Maastrichtian and the others which co-occured with them in the same beds as reworked (an idea ultimately derived from Milovanovic, see below) - a hypothesis which seems rather unlikely.

From the Carpathian Mountains in Slovakia *Pseudopolyconites* is again recorded along with a new genus of rudist called *Bystrickya* . The sediment adhering to the fossil yielded the following foraminifera: *Globotruncana stuarti* (de Lapparent), *Gl. linneana* (d'Orb.), *Gl. elevata* (Brotzen) *Rzehakina* sp. *Miliammina* sp. which according to J. Sandulescu, Bucarest (cit. Lupu, 1976) are characteristic of the Campanian-Maastrichtian.

The Hungarian fauna of Balkony Mountain comprises three rudist zones, the second with *Praeradiolites hoeningshausi, Vaccinites braciensis* and *Hippurites colliciatus* is seen as Upper Campanian and the third with *Hippuritella lapeirousei* and *Agriopleura moroi* as Lower Maastrichtian. There are also other purported Campanian localites. The age assignments are probably on the basis solely of the rudists.

5. Middle Eastern Region

5.1 Turkey

As the rudist fauna of Turkey has been described from collections with little relation to field localities most of the dating is based on the reported occurrence of those rudist elsewhere. There is one exception to this in the orbitoids found in sections of the specimens of *Dictyoptychus* . Thus Karacabey-Öztemür's *Dictyopychus orontica* is known to occur with *Orbitoides media, Siderolites calcitrapoides* and *Omphalocyclus macroporus* and *D. euphratica* with those species as well as a species of *Loftusia* which constrains them to the planktonic foraminiferal Maastrichtian.

5.2 Southern USSR, Iran & Afghanistan

From the first of Douvillé's Iranian localities comes a species of the larger foraminifer *Loftusia, L. persica* Carpenter and Brady, (a large species at up to 8cm in length). In the same area was a loose specimen of a rudist called by Douvillé *Polyptychus morgani* , now the genus *Dictoptychus* and a specimen called *Thyrastylon persicus* by Chubb (1956) which is an otherwise Caribbean radiolitid genus. Douvillé at first thought that these beds were Senonian (which for him excluded the Maastrichtian), but more precisely Santonian, though he later revised this to Maastrichtian in a footnote (Douvillé, 1904). *Loftusia* is now thought to be an exclusively "Maastrichtian" genus (Fleury *et al.*, 1990).

A second locality the "couches à échinides" yielded a specimen called *Biradiolites austinensis* by Douvillé, now regarded as a *Durania* species. In the same unit were the ammonites called: *Sphenodiscus acutodorsatus* and *Heteroceras* (now*Bostrychoceras) polyplocum* . Douvillé thought that this level was Campanian because of a comparison of the echinoid fauna with one of that age from Algeria [though today *B. polyplocum* is seen mainly as Late Campanian].

In the overlying "Couches à cérites" one loose specimen of *Hippurites cornucopiae* Defrance is recorded. The exact stratigraphic level is uncertain, but it probably comes from the lower part of the "Couches à cérites" in beds overlain by marls with *Omphalocyclus macroporus* (called *O. macropora* by Douvillé). The new species of *Loftusia, L. morgani* Douvillé is also from this level.

5.3 Iraq, Syria, Lebanon, Israel & Jordan

I have no biostratigraphic details of these.

6. Arabian Region

6.1 Oman Mountains

Oman Mountains

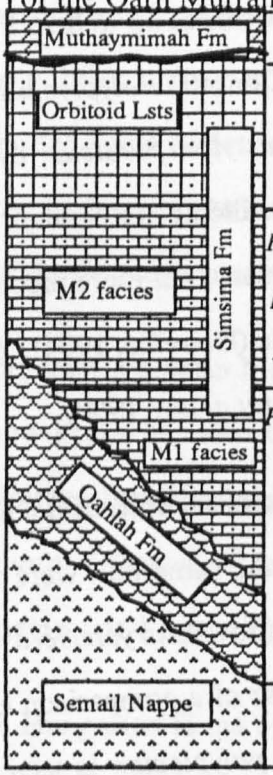
Lithostratigraphy	Biostratigraphy		Chronostratigraphy	
	Rudists	Benthic Forams		
of the Qarn Murrah and Jebel Faiyah areas after Skelton *et al.*, 1990				this work
			Tertiary	
	Biradiolites *Bournonia*	Orbitoids indet.	Maastrichtian	ab-Ma60? abr-Ma40
	Hippurites cornucopiae *Durania* cf.*austinensis* *Dictyoptychus morgani*	*Orbitoides media* *Omph. macroporus* *Lep.* cf.*minor* *Sid. calcitrapoides* *Loftusia* cf.*minor*	Middle Maastrichtian	br-Ca90
	Pironaea ?praeslavonica *Pironaea ?corrugata* *Torreites sanchezi* *milovanovici* *Sabinia* sp. *Colveria* sp. *Durania* cf. austinensis at Jebel Faiyah	*Orbitoides media* *Lepidorbitoides* sp.	Lowermost Maastrichtian-Upper Campanian	br-Ca60

Figure 5/22

The marine transgression over the ophiolite brought the same succession of deposits but they are of different ages in different places (fig. 5/22). Two main faunal associations are noted in Skelton *et al.*, 1990, an M1 and M2 association, the difference between these being primarily stratigraphical because at the locality, Jebel Huwayyah, elements of the M1 fauna are found in a basal conglomerate overlain by beds with an M2 fauna.

The M1 fauna at Qarn Murrah is considered to be of probable Early Maastrichtian age, or may be even Late Campanian. The upper limit of this age estimate is a consequence of the range of *Torreites sanchezi* as recorded in the Caribbean, a subspecies of this form being found at Qarn Murrah (Skelton & Wright, 1987). The lower extension is due to the reported occurrence of *Torreites* in the Late Campanian of the Oman Mountains by Philip & Platel (1987). The broad Late Campanian-lowermost Maastrichtian range is commensurate with the presence of numerous *Orbitoides media* and a few *Lepidorbitoides* . The *Pironaea* specimens from Qarn Murrah most resemble the *P. praeslavonica* which comes from the "Middle Maastrichtian" of eastern Serbia and Bulgaria as recorded by Sladić-Trifunović (1972) and Pamouktchiev (1975). However, Skelton *et al.* also quote the views of Pejović & Radoičić (1987) that even the advanced forms of *Pironaea* may be found in earlier strata, possibly as early as Early Campanian. The presence of *Vautrinia* is also noted. According to Vogel (1970) this has an exclusively Maastrichtian range but this genus is very poorly known.

A "definite Maastrichtian age" is assigned to the M2 fauna according to Skelton *et al.* (1990) because of *Dictyoptychus morgani* and its age as reported by Douvillé (1904). Additionally, following the work of Van Gorsel (1978), Neumann (1980 - both cit. Skelton *et al.*, 1990) and Sladić-Trifunović (1972), the orbitoid assemblage is typical for the upper Lower to lower Upper Maastrichtian. The small size of *Loftusia cf. minor* though suggests a level within the Lower Maastrichtian (Al-Omari & Sadek, 1976, cit. Skelton *et al.*, 1990). The M2 fauna at Jebel Huwayyah and Jebel Rawdah also yielded ammonites. These were identified by W.J. Kennedy as *Pachydiscus (P.) neubergicus* Hauer, and the other as *Neancyloceras?* sp. from Jebel Huwayyah which together indicated to him a Lower to low

Upper Maastrichtian level. From Jebel Rawdah come two significant finds, one *P. (P.) neubergicus* which indicates the Lower Maastrichtian, the other is intermediate between one of the *neubergicus* group and *P. (P.) gollevillensis* and thus of probable 'mid' Maastrichtian age.

Summary and revision of ages

M1 at Qārn Murrah - Rudists and foraminifera can not give an age further constrained than early Campanian - early Maastrichtian but most probably late Campanian. **Ca60-Ca90**

M2 at Jebel Faiyah - Range of the foraminifera is equivalent to the planktonic foraminiferal Maastrichtian. At the other localities this facies reaches the middle Maastrichtian. **Ma0-Ma40**

6.2a Southern Oman

Figure 5/23 adapted from Philip & Platel, 1987 shows the essential biostratigraphic markers for the upper part of the Sanham Fm and the Sharwayn Fm. The Sanham Fm also contains the smaller foraminifera *Montcharmontia apenninica* De Castro and *Minouxia conica* Gendrot as well as ostracods. On the basis of the foraminifera, the Sanham Fm is thought to be Campanian, probably Late Campanian in age. The rudist genus *Torreites* is also found in the Sanham Fm. This otherwise Caribbean form has been recorded from eastern Tethyan localities in the Maastrichtian of northern Oman by Grubić (1979 - cit. Philip & Platel, 1987) [as well as by Skelton & Wright, 1987 in the U.A.E.]. In the Caribbean *T. sanchezi* is particularly abundant in the Campanian - Maastrichtian of Jamaica and *T. tschoppi* is recorded from the Santonian of Cuba (cit. Philip & Platel, 1987). The Sharwayn Fm was given an unequivocal Late Maastrichtian age by Philip & Platel.

Summary and revision of ages

Top of Sanham Fm - Probably late Campanian. **Ca50-Ca60**

Limestone of the Sharwayn Fm - Co-occurrence of *O.macroporus, Loftusia* and *Hellenocyclina* sp. suggests a level relatively high in the Maastrichtian. **Ma30-Ma60**

6.2b Central Saudi Arabia

S. Oman

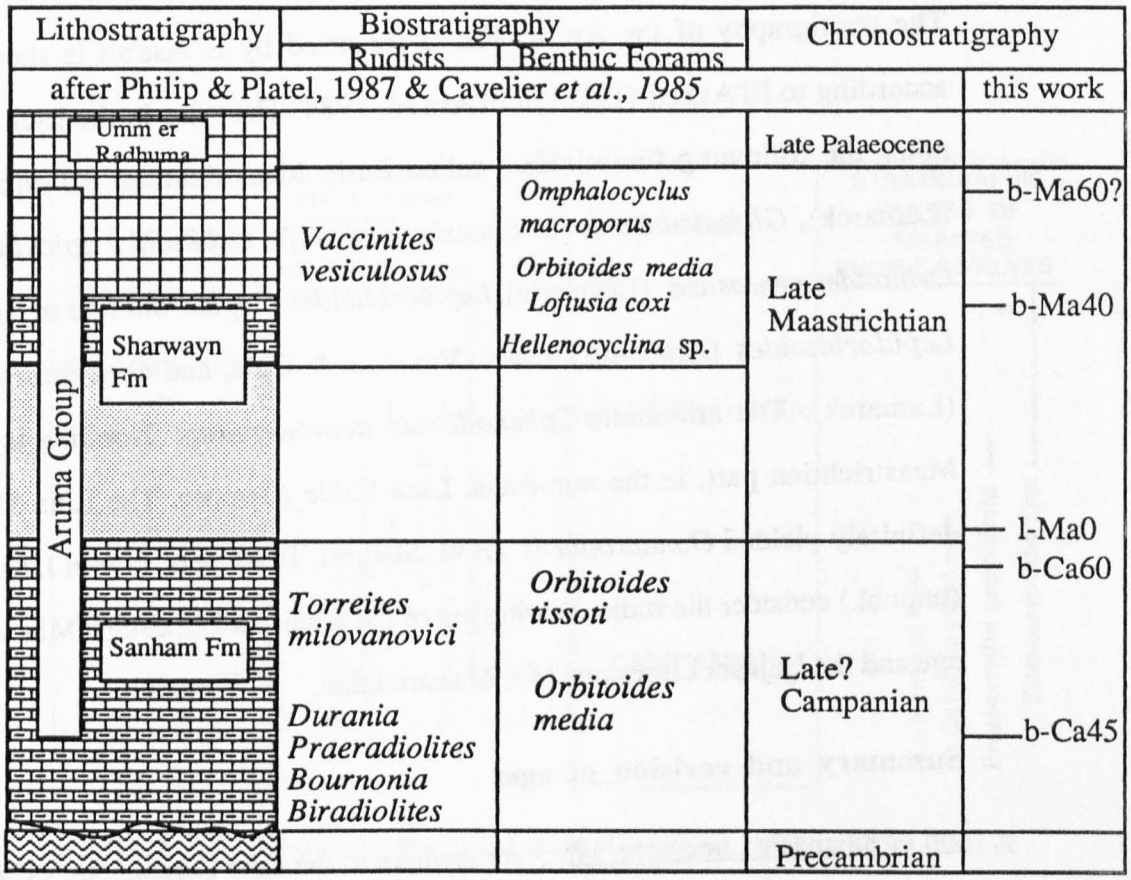


Figure 5/23

Central Saudi Arabia

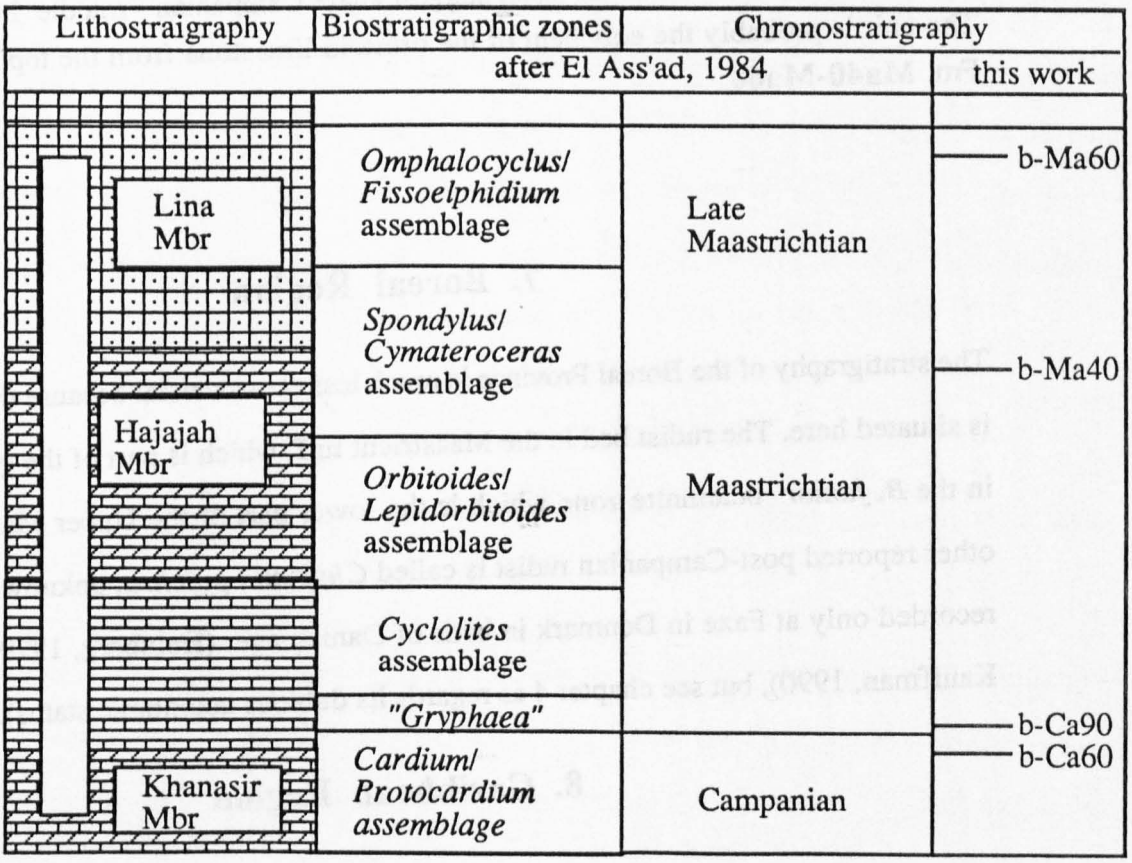


Figure 5/24

The stratigraphy of the Aruma Fm as recorded by El'Asa'ad is shown in figure 5/24, according to El'Asa'ad (1977) in El'Asa'ad, 1984. The table in the back of El Asa'ad, 1984 notes the following foraminifera called Early Maastrichtian: *Rotalia* cf.*trochidiformis* (Lamarck), *Globotruncana havanensis* Voorwijk, *Orbitoides apiculata* Schlumberger, *Orbitoides gensasicus* (Leymerie), *Lepidorbitoides (Lepidorbitoides macgillavryi* Thiadens, *Lepidorbitoides (Asterobis) rooki* Vaughan & Cole, and *Omphalocyclus macroporus* (Lamarck). The ammonite *Sphenodiscus acutodorsatus* Noetling is noted in the Late Maastrichtian part, ie the non-rudist Lina Shale Member. The Lina Shale Mbr has also definitely yielded *O.macroporus* (P.W. Skelton, 1990, pers. comm.). Skelton & El Asa'ad (unpubl.) consider the rudist-bearing top of the Khanasir Limestone Mbr to be Campanian in age and the Hajajah Limestone Mbr Maastrichtian.

Summary and revision of ages

top of Khanasir Limestone Mbr - somewhere in the Late Campanian. - **Ca60**

Hajajah Limestone Mbr - the orbitoids suggest late Campanian - early Maastrichtian. **Ca90-Ma40**

Lina Shale Mbr - the orbitoids again suggest a late Campanian - middle Maastrichtian age. The unit is probably the eqivalent of the orbitoid limestone from the top of the Sharwayn Fm. **Ma40-Ma60**

7. Boreal Region

The stratigraphy of the Boreal Province is much less controversial because the type sequence is situated here. The rudist bed in the Maastricht tuff, which is part of the type sequence, is in the *B. junior* belemnite zone which is the lower part of the Upper Maastrichtian. The other reported post-Campanian rudist is called *Chypiella pulchra*, unknown in Tethys and recorded only at Faxe in Denmark in beds of Danian age (Heinberg, 1979 cit. Johnson & Kauffman, 1990), but see chapter 4 as regards its dubious taxonomic status).

8. Caribbean Region

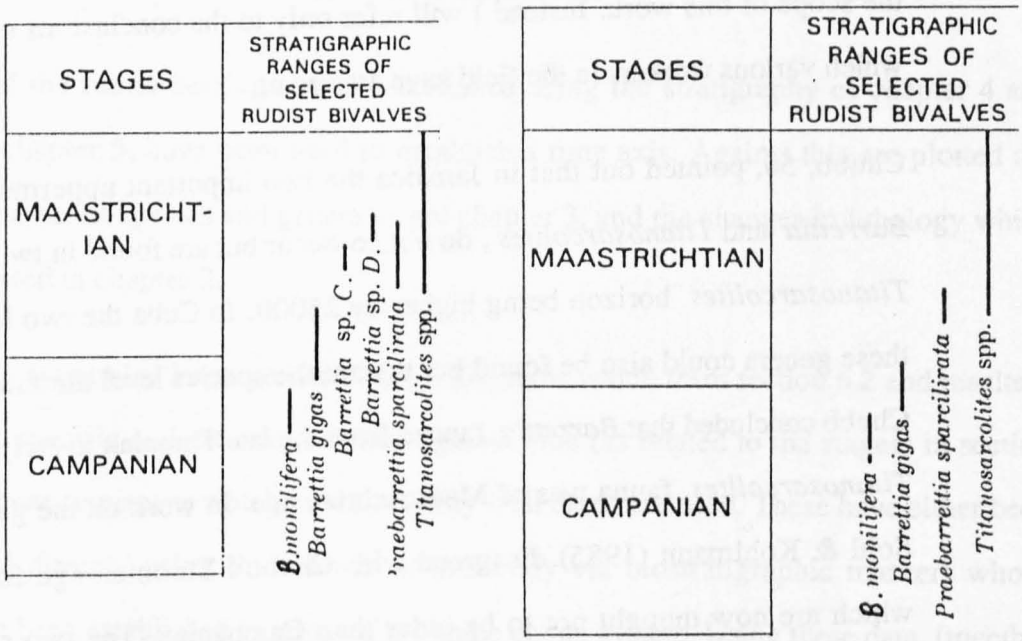


Figure 5/25. Rudist ranges in i) Puerto Rico & ii) Jamaica from Sohl & Kollmann, 1985

A detailed discussion of the biostratigraphy of the rudist beds of the Caribbean, which forms a separate palaeobiogeographic province for rudists in the Late Cretaceous, is outside the scope of this work. Instead I will refer only to the conclusions of the ages of the beds, which various workers in the field have arrived at.

Chubb, 56, pointed out that in Jamaica the two important uppermost Cretaceous genera, *Barrettia* and *Titanosarcolites* , do not co-occur but are found in two distinct horizons, the *Titanosarcolites* horizon being higher by 2500ft. In Cuba the two levels characterised by these genera could also be found but that, at the species level the fauna was very different. Chubb concluded that *Barrettia* ranged from the late Turonian to early Senonian and that the *Titanosarcolites* fauna was of Maastrichtian age. In work on the gastropod assemblages, Sohl & Kohlmann (1985) disagreed with Chubb's Turonian age for the *Barrettia* beds which are now thought not to be older than Campanian. The two range charts shown in figure 5/25 come from that work.

The American rudist workers Kauffman & Johnson, (eg. Kauffman, 1988; Johnson & Kauffman, 1990;) claim to have correlated the rudist horizons of the Caribbean with the planktonic foraminiferal stratigraphy. They claim to see a pattern of "stepwise mass extinction" of the Maastrichtian rudist fauna within the *mayorensis* zone at the top of the Maastrichtian (Kauffman, 1988; Hut *et al.*, 1987) in the Caribbean fauna. In the first extinction event 24 genera and 83 species of rudists that were present near the "Upper/Lower Maastrichtian boundary" disappeared within the lower part of the *mayorensis* zone. The second step, in the middle of the zone accounted for the radiolitids and hippuritids. The third step, 0.05-0.1m.y. before the boundary saw the extinction of the "last giant solitary rudists" such as *Titanosarcolites*. According to these authors (eg. Kauffman, in Hut *et al.*, 1987) the rest of the rudists were extinguished at the K/T boundary [although this remark may not apply to the Caribbean].

Chapter 6: Conclusions

6.1 Introduction

The ages of the rudist-bearing strata, established using the stratigraphy of chapter 4 and applied in chapter 5, have been used to establish a time axis. Against this are plotted the ranges of the rudist species and genera as per chapter 3, and the changes in lithology which were discussed in chapter 2.

The data are assembled into a series of range diagrams which form section 6.2 and resultant plots of the specific and generic diversity against time (as related to the stages) in section 6.3. Only those sequences which are reasonably well dated are used. These have either been either dated directly using Sr-isotopes or indirectly via biostratigraphic markers whose ranges have been established in terms of the same dating system. Using these data, (together with some from outside Tethys), the timing of the rudist extinctions is discussed.

Section 6.4 is concerned with the relationship between rudist extinction and facies change. This is demonstrated in a plot of the proportions of non-marine/marine/pelagic strata/non-deposition through time for these sequences from the Tethys margins. Using all the data on rudist occurrence - even that where the age of the fauna is relatively vague - a map has been drawn of the palaeobiogeography of rudists and certain larger benthic foraminifera for the late Campanian-Maastrichtian interval. This is presented in section 6.5. The final conclusions as to the cause and mode of the extinction of the entire group of rudist bivales form section 6.6.

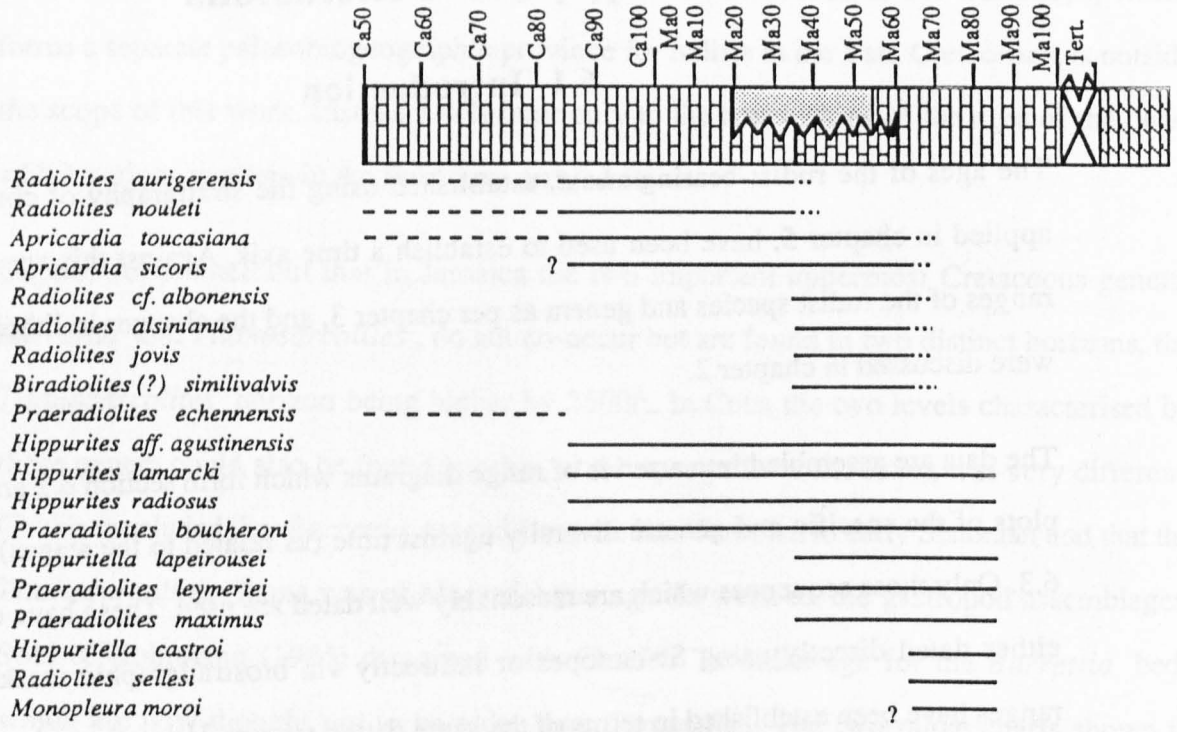
6.2 Ranges of rudist species

The local ranges of the late Campanian-Maastrichtian rudists in certain, relatively well dated sequences, are plotted in figure 6/1.

Total ranges (including interpolated portions) of these genera of rudists and of certain larger benthic foraminifera of European-African-Asian Tethys are shown in figure 6/2. The ranges are related to the commonly used planktonic foraminiferal C/M boundary (~Ca86) and to the

1. PYRENEES

French Prepyrenees (1.1ai) and Spanish Catalonian Pyrenees (1.1b)



Montsech & Tremp Basin, Spanish Pyrenees (1.1ai)

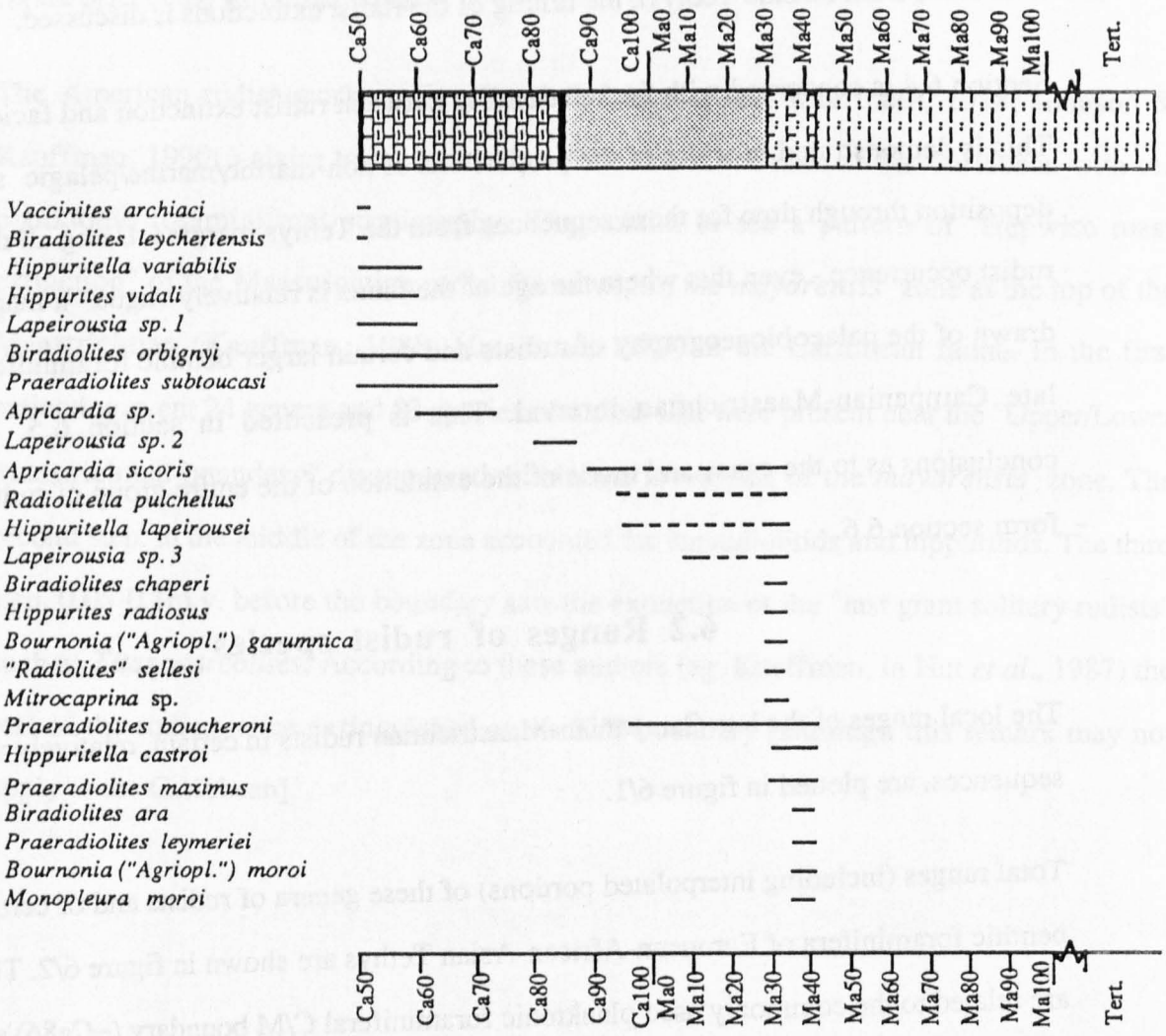


Figure 6/1 Ranges of rudist species. i) French Prepyrenees & Catalonian Pyrenees, ii) Montsech & Tremp Basin, Spanish Pyrenees

Adriatic Platform: M. Jouf, N. Italy (2.2a)

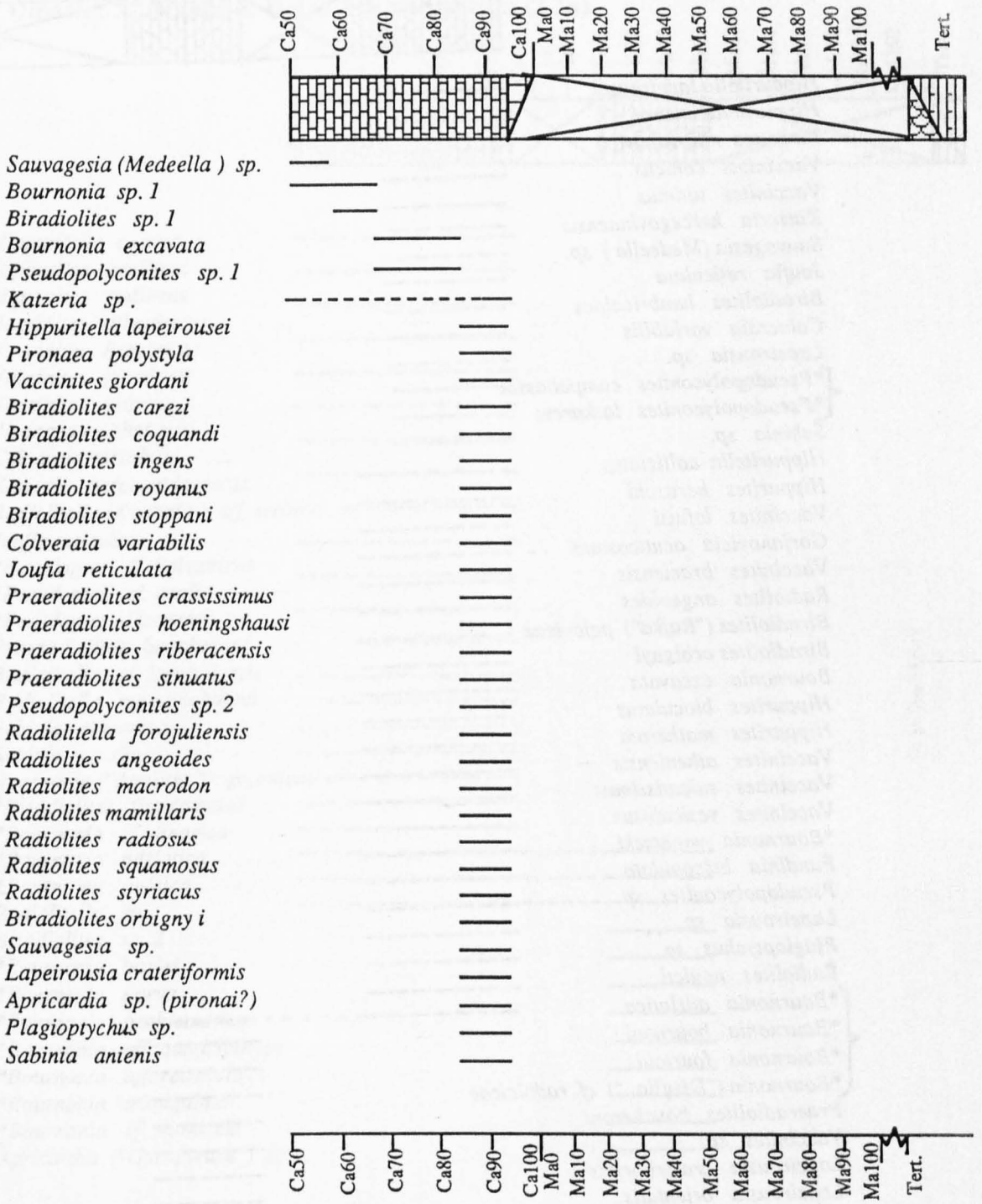


Figure 6/1 Ranges of rudist species. v) M. Jouf, N. Italy

Dinaric Platform: Brač Island, Croatia (2.2b)

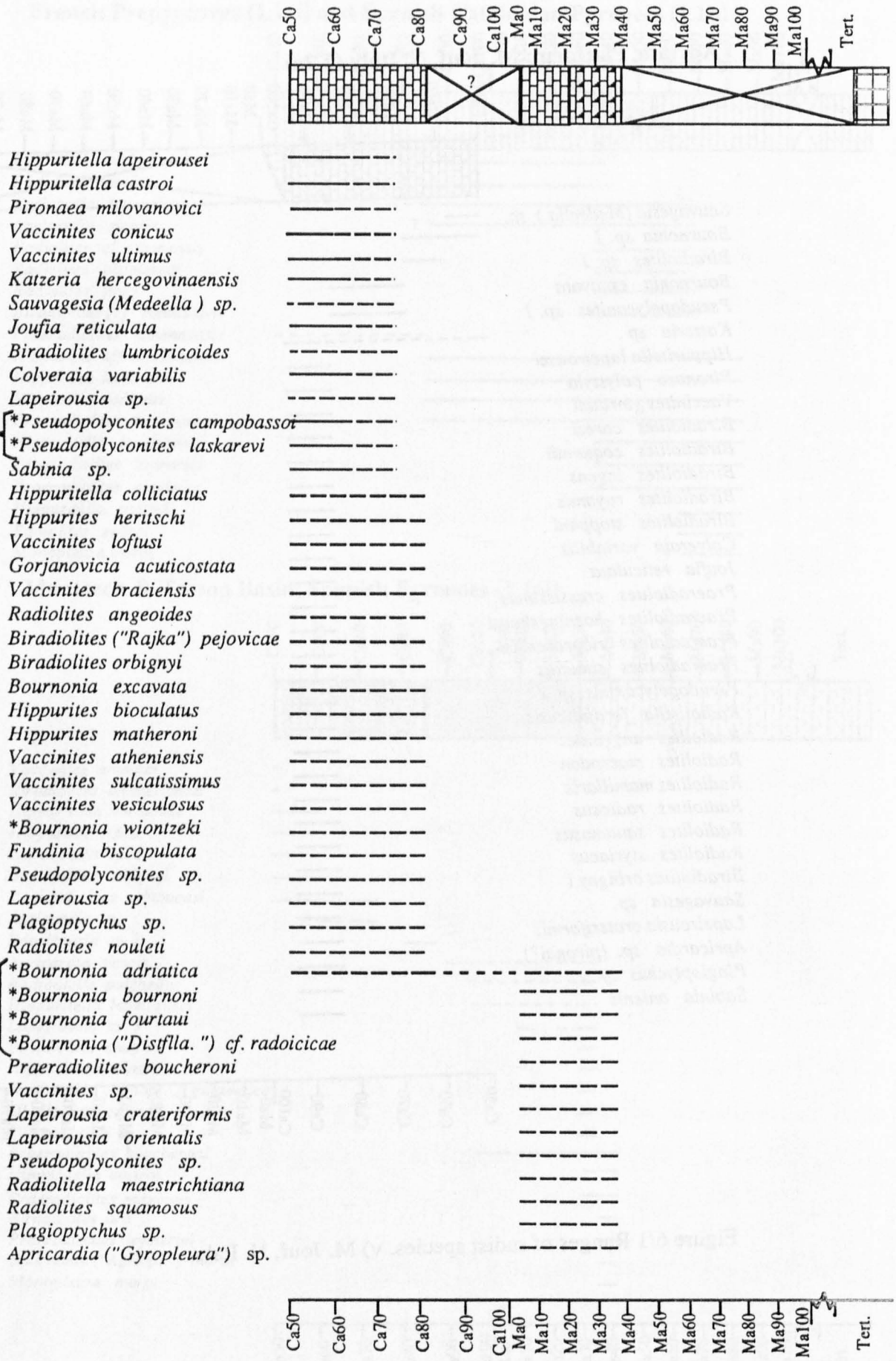


Figure 6/1 Ranges of rudist species. iii) Brac Island, Croatia

2. PERIADRIATIC

Dinaric: M. Nanos & Dolenja Vas, Slovenia (2.1a)

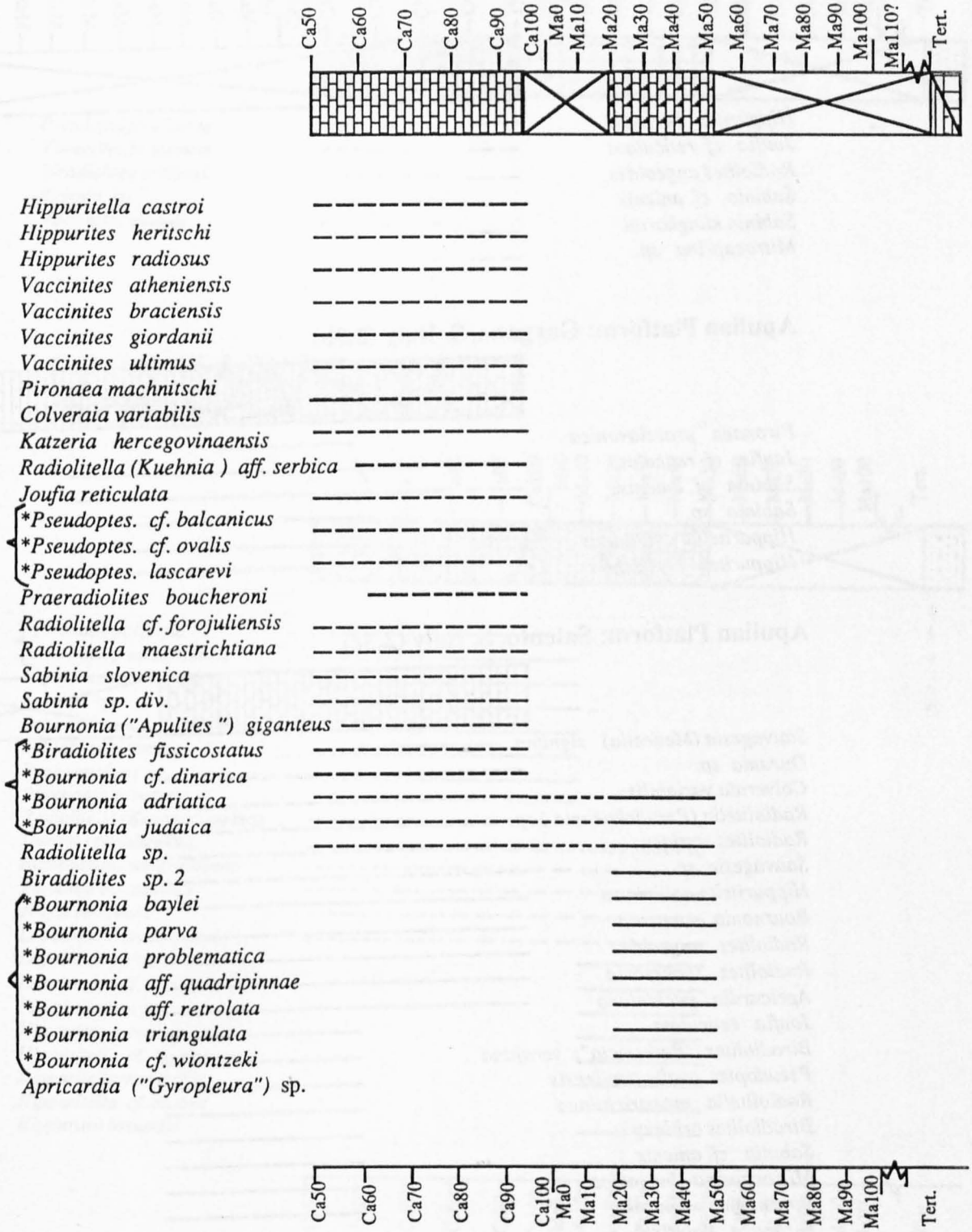
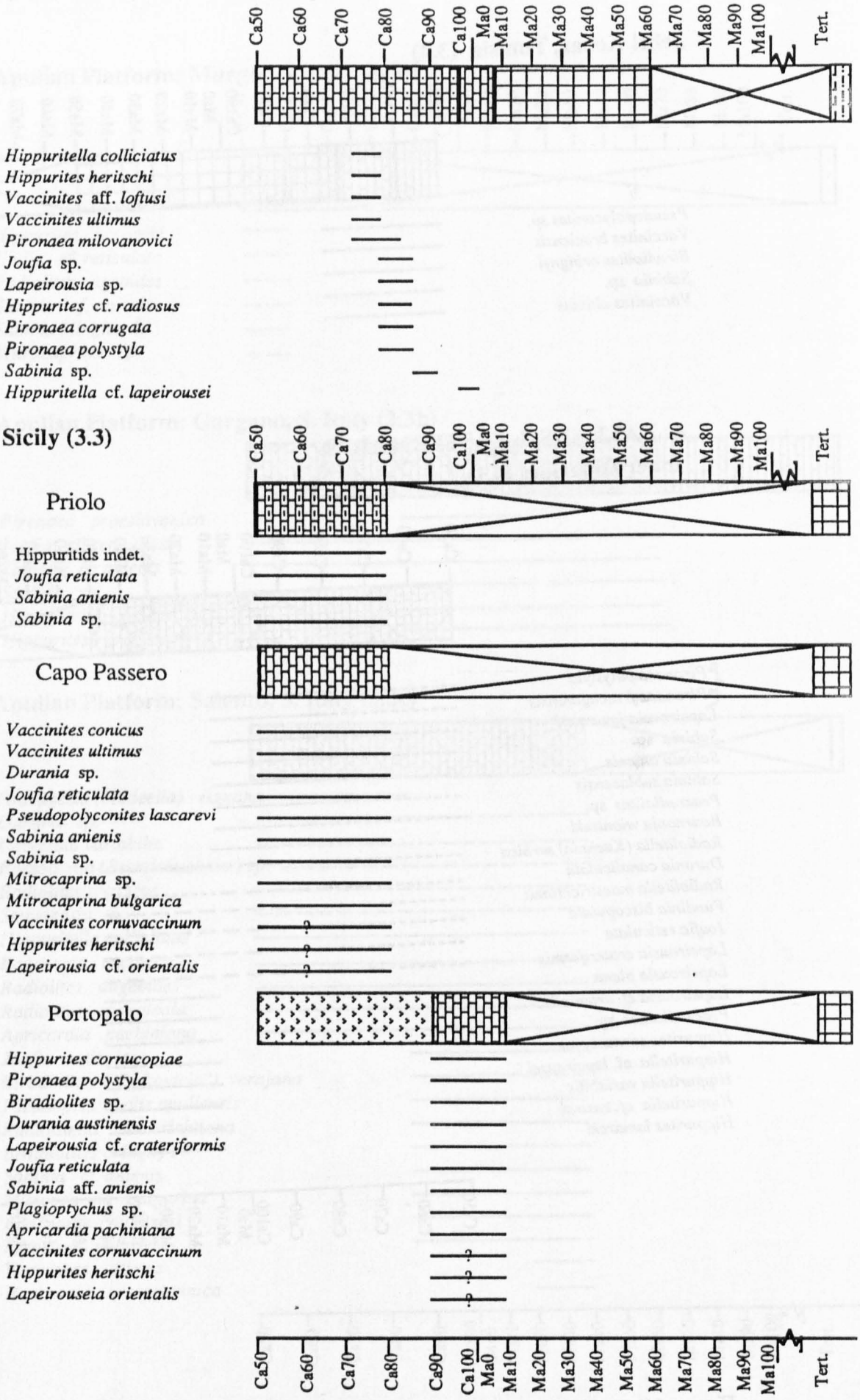


Figure 6/1 Ranges of rudist species. iii) M. Nanos & Dolenja Vas, S. Slovenia

3. N. AFRICA

Quatretonda, S. Valencia, S. Spain (3.1)



Sicily (3.3)

Figure 6/1 Ranges of rudist species. ix) Quatretonda, S. Spain, x) Sicily

Eastern Serbia (4.2a)

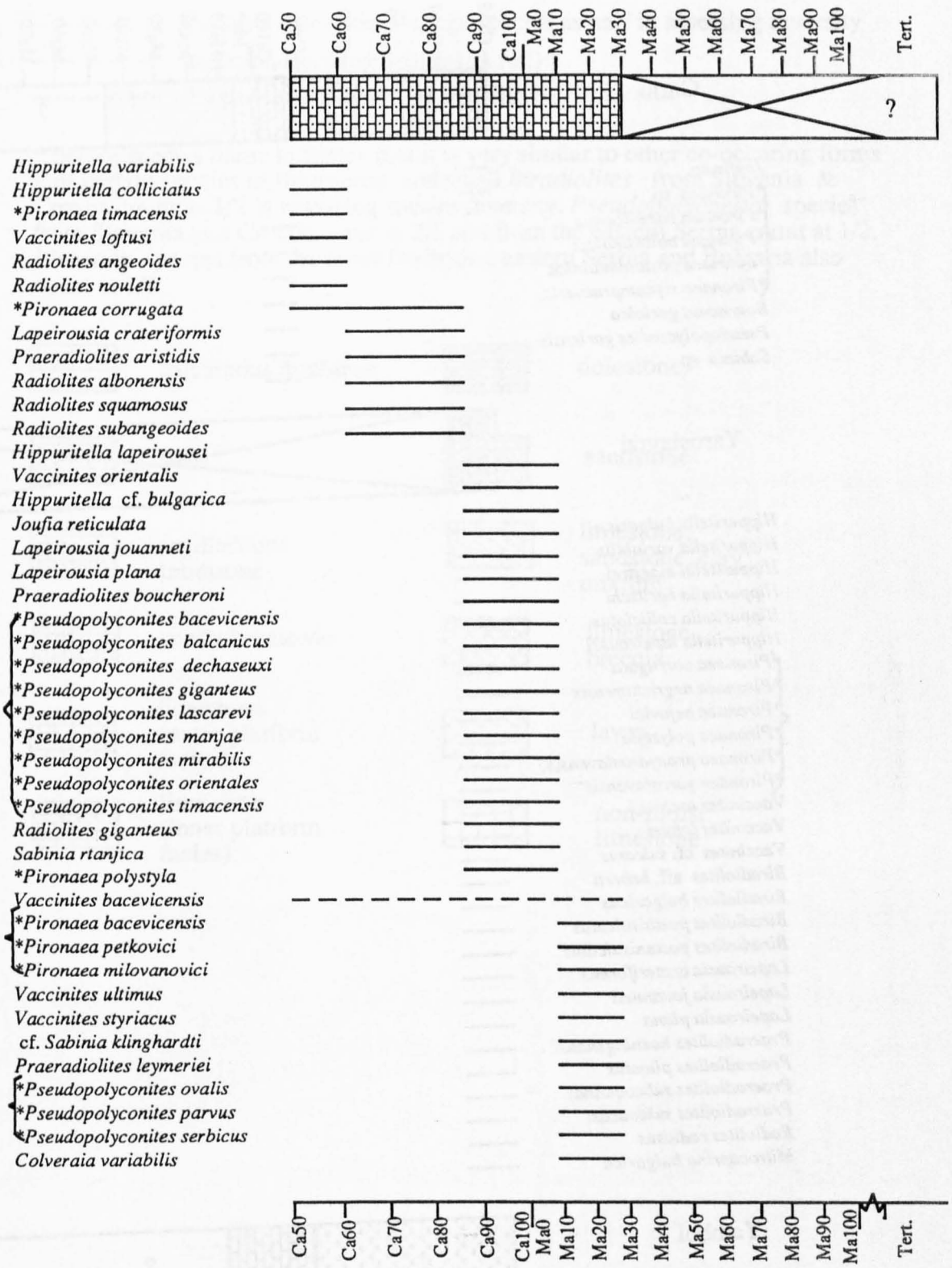


Figure 6/1 Ranges of rudist species. xii) Eastern Serbia

Bulgaria (4.2b)

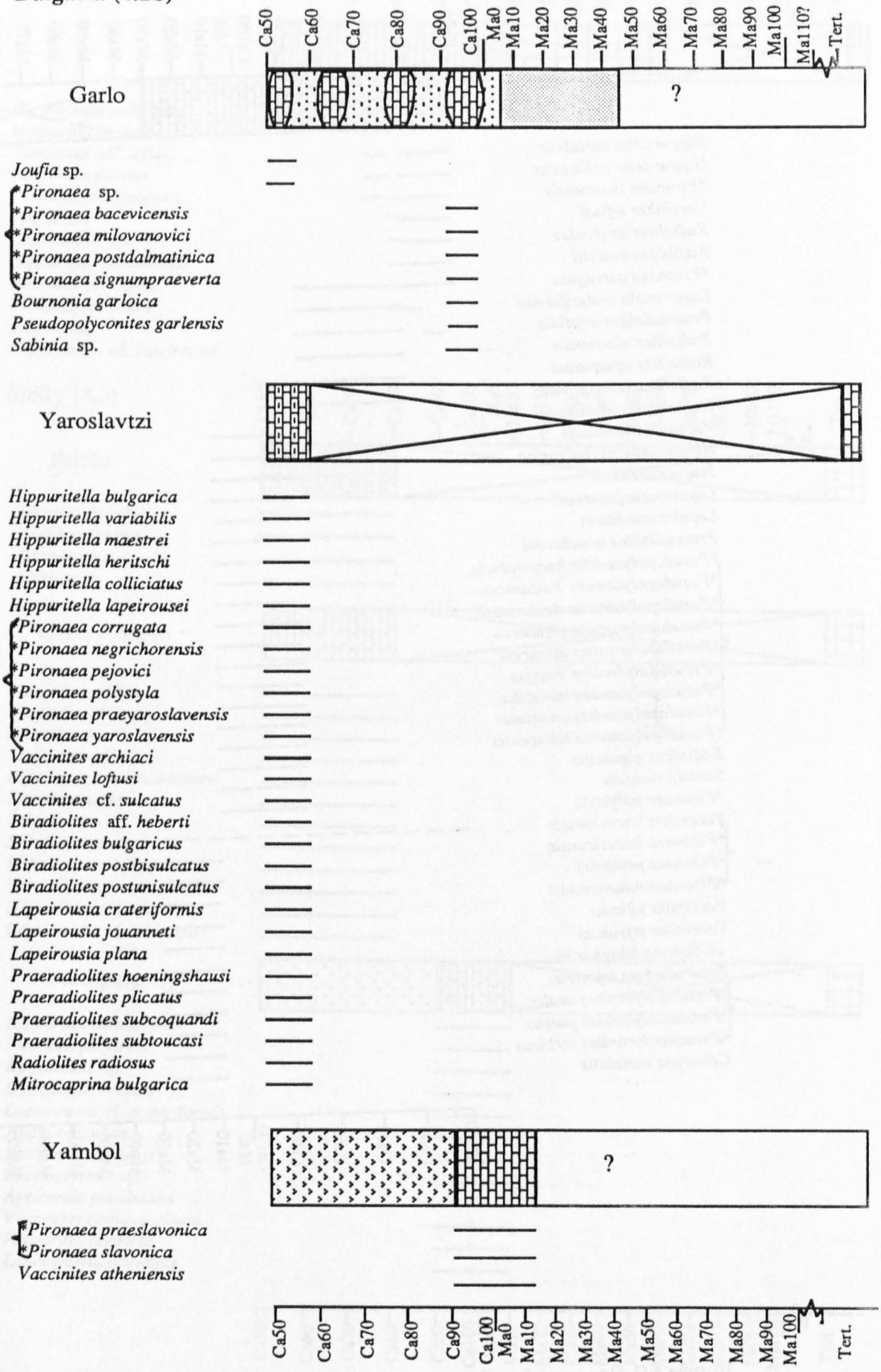


Figure 6/1 Ranges of rudist species. xiv) Bulgaria

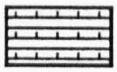
Key to figure 6/1

..... Possible extension of range (counts as half in assessing diversity

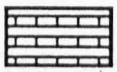
– – – – – Interpolated range (counts as full)

——————· Vague range (counts as two thirds)

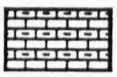
* before species name indicates that it is very similar to other co-occuring forms thus certain species of *Bournonia* and small *Biradiolites* from Slovenia & Croatia count as 1/2 in assessing species diversity. *Pseudopolyconites* species from Slovenia and Croatia count at 2/3 and from the eastern Serbia count at 1/2. *Pironaea* species from the Inner Dinarides, eastern Serbia and Bulgaria also count at 1/2.



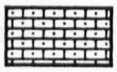
calcareous mudstone



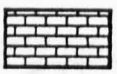
marl



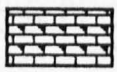
argillaceous limestone



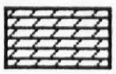
sandy limestone



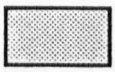
limestone (outer platform facies)



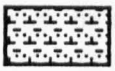
limestone (inner platform facies)



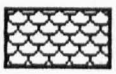
dolostone



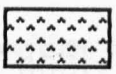
sandstone



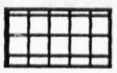
limestone, sandstone, clay mixture



limestone breccia



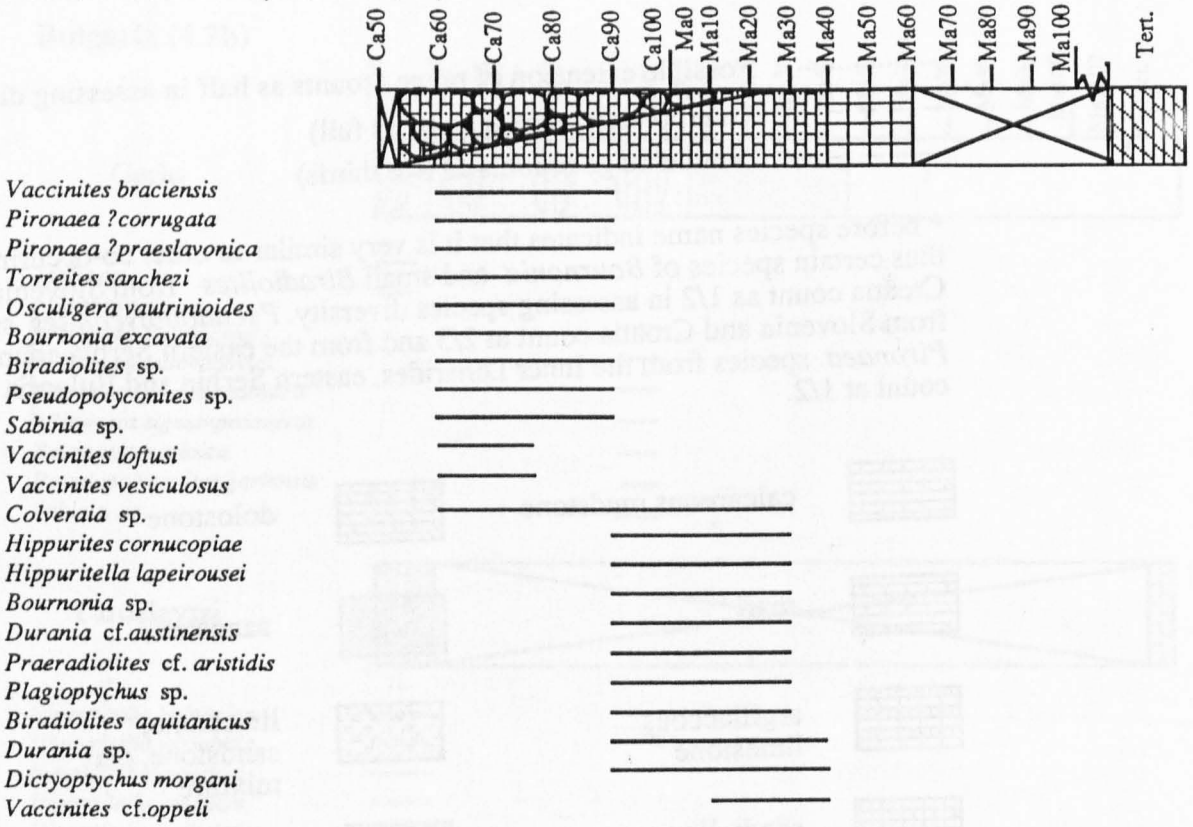
lavas



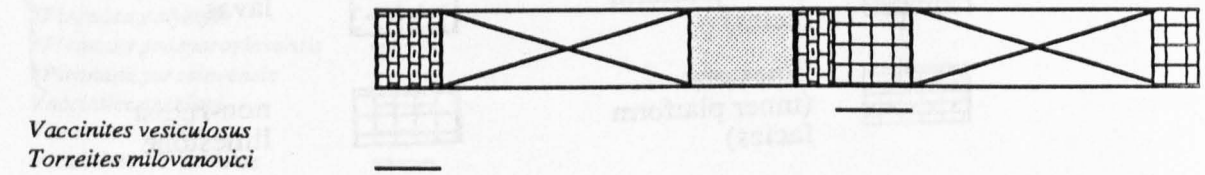
non-rudist limestone

6. ARABIA

Oman Mountains, U.A.E. (6.1)



S. Oman (6.2a)



Central Saudi Arabia (6.2b)

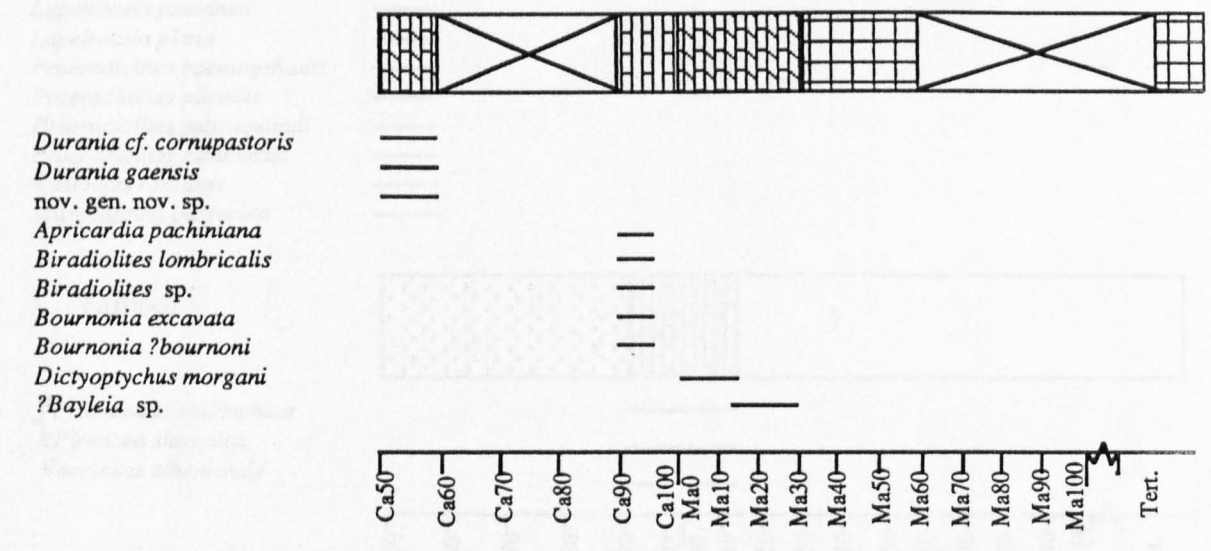


Figure 6/1 Ranges of rudist species. xv) Oman Mnts, U.A.E., xvi) S. Oman, xvii) Central Saudi Arabia

the C/M boundary at the base of the Maastrichtian of the type area (by definition Ca100/Ma0). The following points concerning these ranges are thought significant:

1. The central and eastern Tethyan rudist fauna of *Sabinia-Joufia-Colveraia-Pironaea-Pseudopolyconites* which has frequently been used as an indicator of Maastrichtian strata dates back almost to the start of the Campanian (as dated at Garlo, Bulgaria (see section 4.4.2f) and in the Brač marble in Croatia (4.4.2c), using Sr isotopes, and from the planktonic foraminifera of surrounding beds at Jebel Serraguia, Tunisia (Bernet-Rollande & Philip, 1981) and extends upwards certainly as far as Ma40, possibly to Ma65. In the majority of cases it is late Campanian in age.

2. In Tethyan sequences the orbitoids *Siderolites calcitrapoides, Lepidorbitoides minor* and *Omphalocyclus macroporus* range from Ca84, or even Ca80, a level very close to the planktonic foraminiferal boundary (which is perhaps more like Ca86) to the end of the Maastrichtian shallow marine facies in which they occur. Their range in the French Pyrenees - where they dominate the fauna in strata of Late Maastrichtian age (Bilotte, 1985) and probably range as far as Ma92 - is atypical. They are equally well known in the Early Maastrichtian beds (using the Boreal C/M boundary) are also found in beds of Late Campanian age.

6.3 Rudist diversity against time and timing of the extinctions

Figure 6/3 is based on the range charts of figure 6/2 and shows plots of the the diversity/time for the separate different geographical areas and for these combined. They use a compilation of the ranges of rudists from the various selected sequences and include interpolated ranges.

The graphs show that the diversity reaches a maximum and then falls into, a generally steep, decline. However, as that steep portion is at different times in different places the overall diversity/time plot shows a gradual decline. There is also a consistent difference in the pattern of diversity as seen at the specific and at the generic level. Seen from the plots of total diversity, the generic diversity shows that the maximum was achieved in the middle of the Campanian, falls gradually and then more steeply: at the specific level the maximum was at

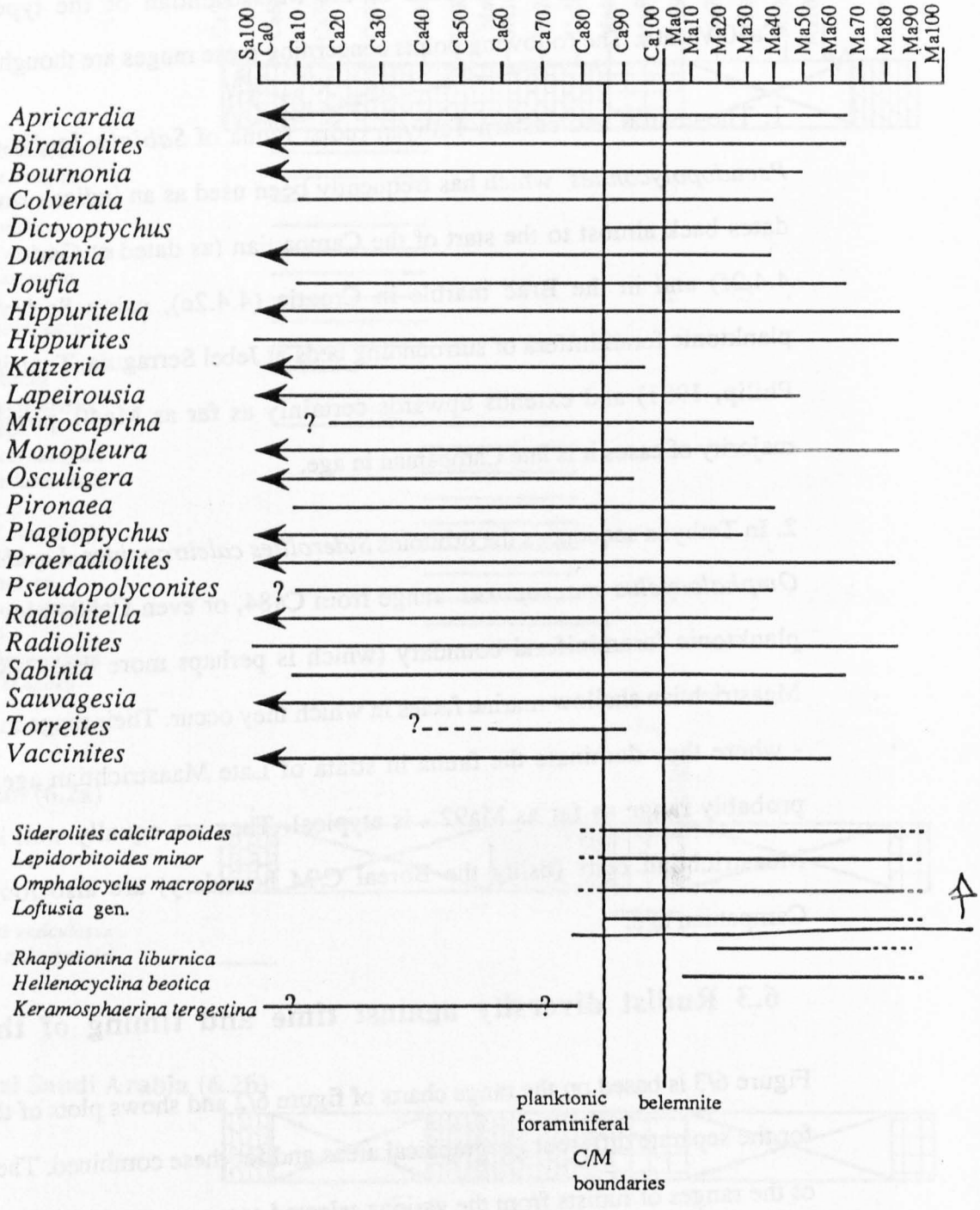


Figure 6/2 Ranges of Rudists and certain benthic foramnifera

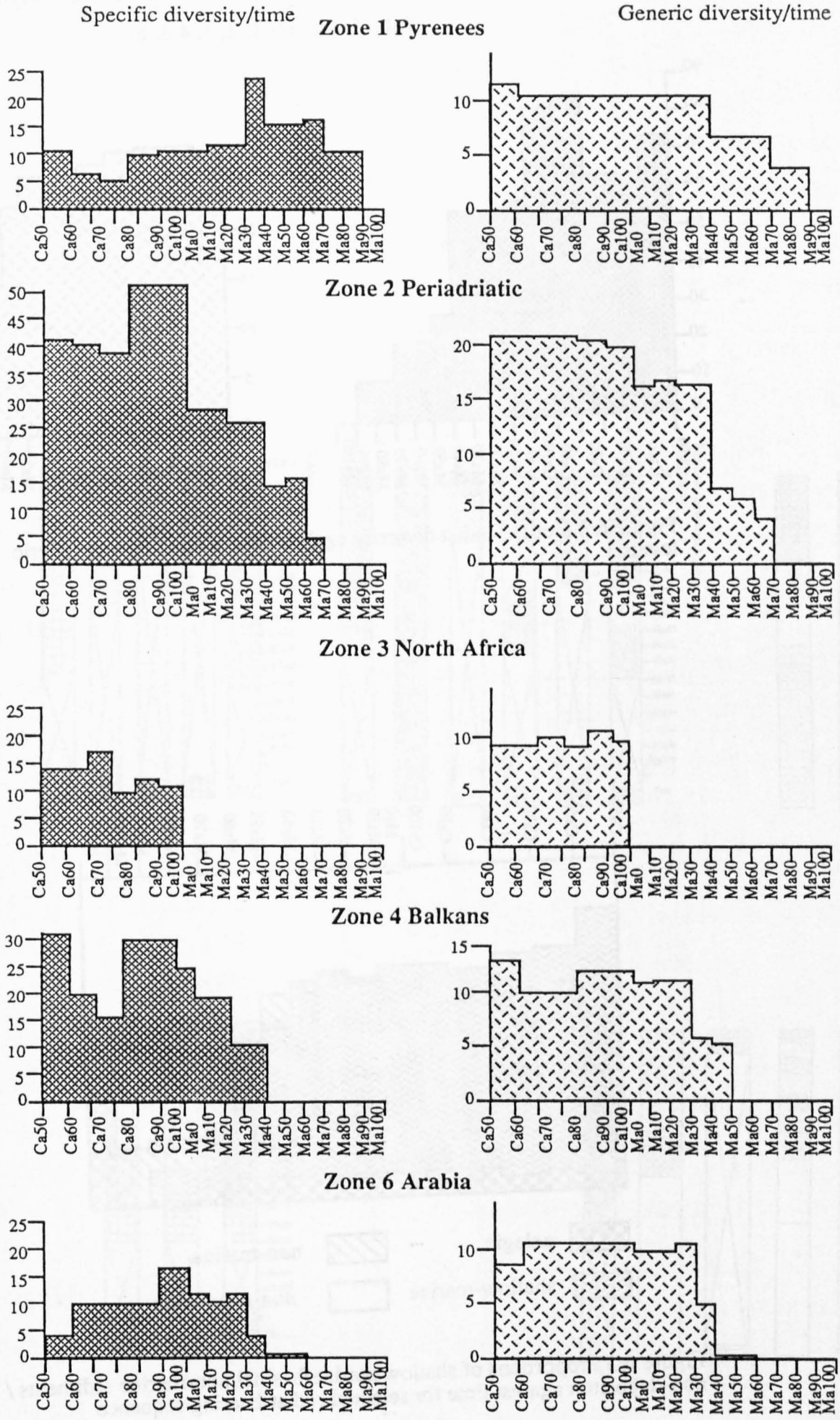


Figure 6/3. Rudist diversity against time at specific and generic levels.

Specific diversity/time Generic diversity/time

Total for zones 1, 2, 3, 4 & 6

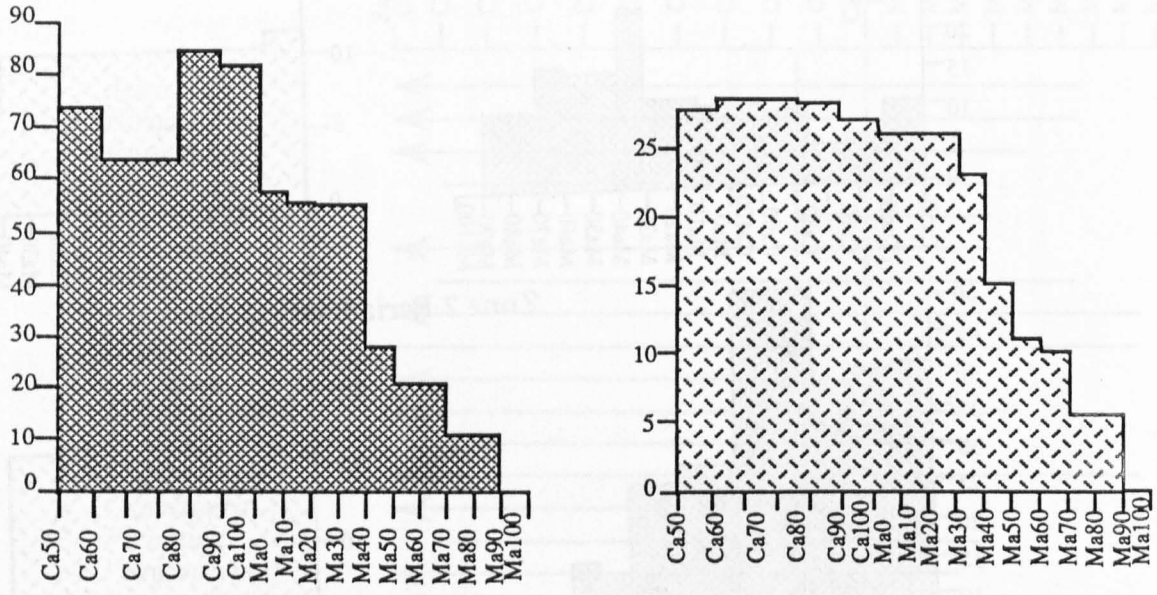


Figure 6/3 (cont). Rudist diversity against time at specific and generic levels.

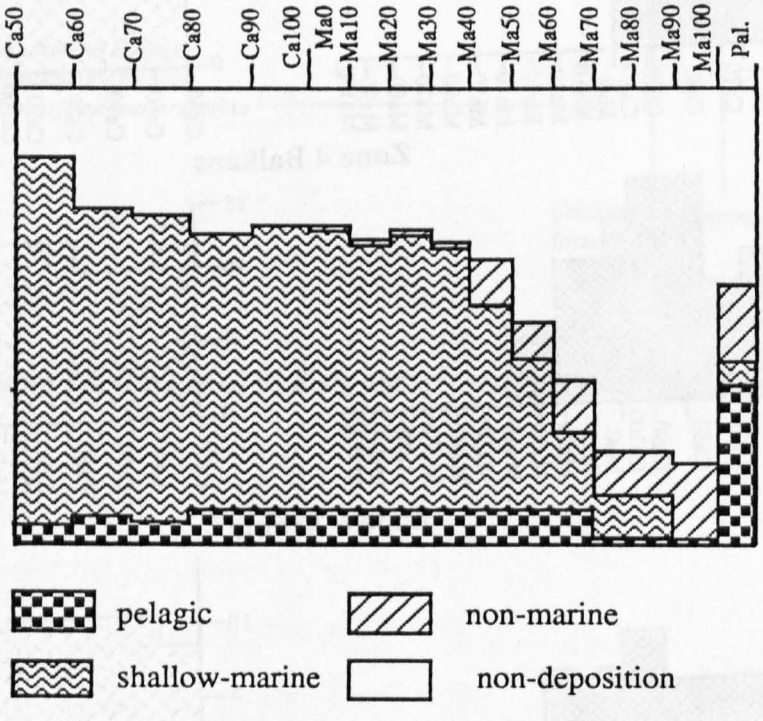


Figure 6/5 Proportions of shallow marine/basinal/non-marine sediments / non-depositon against time for selected rudist-bearing sequence

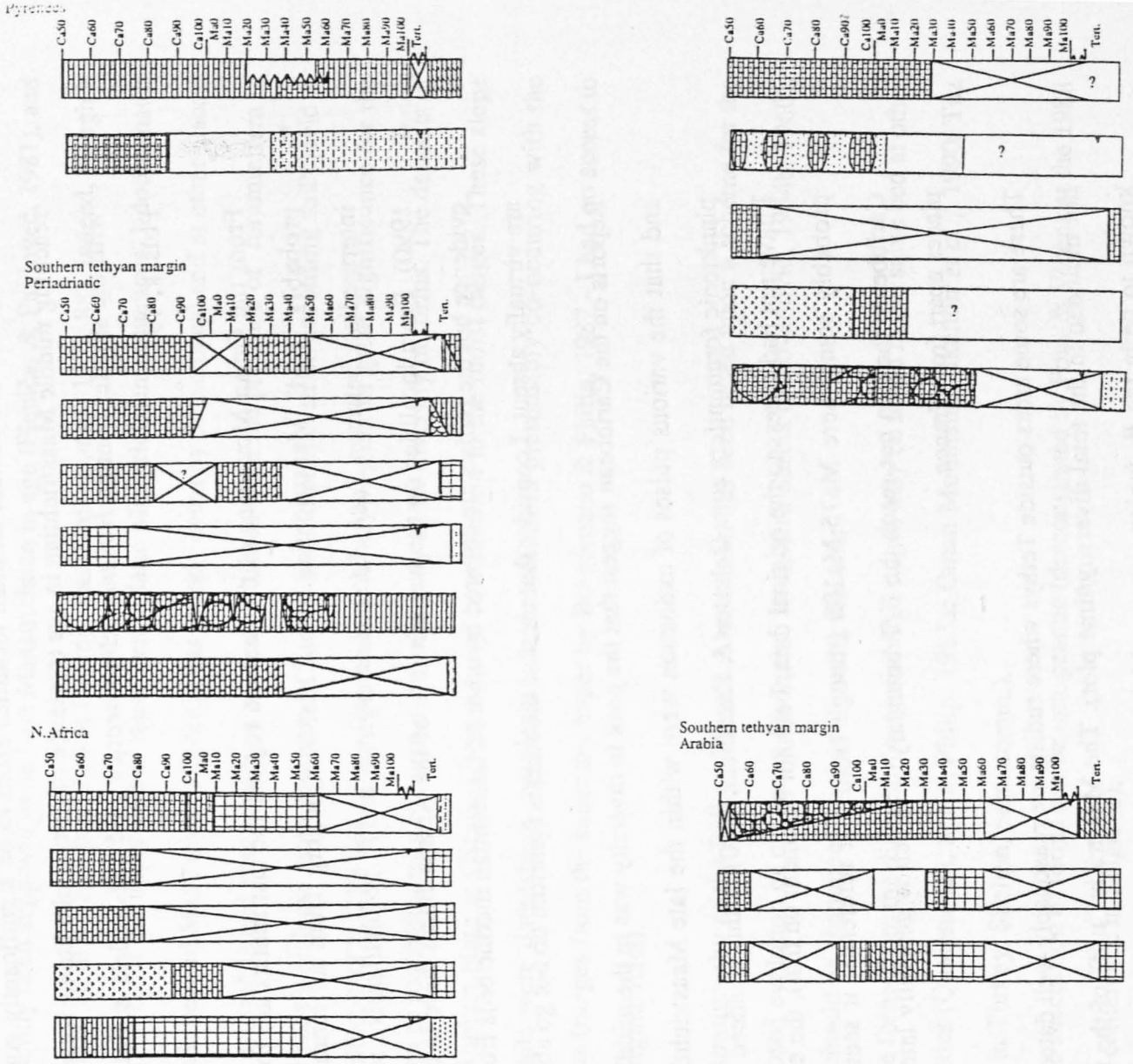


Figure 6/4 Sedimentary sequences of the Tethyan margins. All the sequences show evidence of a regression in the Maastrichtian. Most also show a shorter transgressive phase immediately after the deposition of the last main rudist limestone.

The scheme had divided the "Maastrichtian" strata of eastern Serbia into three units, called lower, middle and upper Maastrichtian, which presupposed that the succession was complete up to the K/T boundary, which is very unlikely. Comparisons with very similar beds exposed in the adjacent territory of western Bulgaria suggest that the beds terminate at a level around Ma28 (dated with reasonable confidence by Sr-isotopes, an answer which agrees with the new orbitoid finds, Swinburne, Bilotte & Pamouktchiev, in prep.).

The sequences of the Inner Dinarides are part of a different structural area and were probably formed at some distance to those in eastern Serbia thus they cannot be assumed to be of the same age. Indeed certain Bosnian localities seem to be significantly younger - probably reaching middle Maastrichtian in age (presence of certain planktonic foraminifera together with the smaller benthic *Hellenocyclina beotica* , Dévidé-Nedela & Pol£sak, 1961 - cit. Polšak, 1965).

From the Oman Mountains of the Arabian region, the last rudists are found in a unit of probably "mid" Maastrichtian age - Ma30? (judging from an ammonite specimen intermediate between *Pachydiscus neubergicus* and *P. gollevillensis* , see Skelton *et al,* 1990). From localities on the western side of the Aruma Basin there is little precise age evidence but the rudists are covered by other Maastrichtian marine beds from which rudists are virtually absent. I consider that most of the rudists therefore do not go above Ma40.

Reports on the Caribbean suggest that the peak in diversity was in the middle Maastrichtian and that the various pulses of extinction were within the late Maastrichtian *mayorensis* planktonic foraminifera zone (Johnson & Kauffman, 1990). If this is indeed the case (and as I have not had access to the original data, I cannot comment on that), the extinctions were probably somewhere Ma75-Ma100 (though from that reference, it seems as if in the Caribbean, they do not reach the K/T boundary) - which is generally later than in other places apart from France.

There are some areas outside Tethys where rudists are reasonably well dated (but these are not included in the total diversity/time plot). The Maastricht "tuff" of the type sequence, known to be in the *B. junior* zone, which is Ma35-68 (zone dated by Sr-isotope from

the end of the Campanian and there was a constant decline until the end of the Maastrichtian.

The last major rudist fauna is from the French Petites Pyrenees in the Marnes d'Auzas. The rudist-bearing beds terminate at a level of around Ma85 (as indicated by the planktonic foraminifera assemblage of Bilotte, 1985, and relatively poor Sr-isotope dates) and are covered by another 180m of Maastrichtian strata. In comparison the Garumnian fauna of the Tremp Formation of northern Spain is significantly older at Ma30-40 (from the planktonic foraminifera of Liebau, 1984 and more precisely from Sr-isotope dates).

In the Periadriatic region the lower part of the Liburnian Formation, or Vreme beds has frequently been supposed to be Late Maastrichtian in age (Pleničar & Pavlovec, 1981), and to extend up to the K/T boundary at Dolenja Vas (Drobne *et al.*, 1987, 88). Indeed, though it does represent the upper part of these Periadriatic Maastrichtian sequences, I doubt that it extends beyond Ma52 even at Dolenja vas (poorly dated by Sr-isotopes) and at other places, such as Brač island may stop even sooner (evidence from the presence of foraminifera in these beds which are more common in Santonian-Campanian strata according to Pejović & Radoičić, 1987). The age of the Vreme beds is anyway not of great significance for the pattern of rudist diversity because it contains only a low diversity of forms. The deposits of the Apulian plate at Gargano have caused an extension to the rudist ranges. These slope deposits were dated from the planktonic foraminifera presumably co-occuring with the rudists (ranges from the summary paper by Borgomano & Philip, 1987 - I had no access to the original data).

The stratigraphy of the Balkan-Eastern Alps region has been based upon a scheme for the supposed evolution of the genus *Pironaea* in eastern Serbia (Milovanović, 1934b, 1960). This should be abandoned for the following reasons:

a) The forms from the different "evolutionary" stages may be found in the same bed at other localities (Quatretonda, Spain, Philip, 1985a; Oman Mountains, Skelton *et al.*, 1990; Tuz Golu in Turkey, Skelton, pers. comm.).

b) The succession of forms can be ontogenetic (demonstrated by Pons & Vicens at the 1988 rudist conference in Belgrade).

North German material) has yielded 5 species, 3 genera. There are also at least two isolated examples of Lower Tertiary rudists. These are *Chypiella pulchra* (a *Gyropleura* ?) from the Lower Palaeocene (Middle Danian) of Faxe, Denmark (Heinberg, cit. Johnson & Kauffman, 1990) and *Paramonopleura* (= *Gyropleura*) from Chelabinsk, USSR (cited in Dechaseux *et al,* 1969)

6.4 Extinction and relationship to habitat change

In all the sequences shown figure 6/3, the demise of the rudists is linked with a facies change at the end of the Maastrichtian. Overall the sequences show a regression in the Maastrichtian Period which resulted in no more potentially rudist-bearing sediments. In many areas, there is evidence for a slight transgression before the final regression and disappearance of the facies.

In sequences from the northern Tethyan margin in the Pyrenees a regression in the Maastrichtian has resulted in a change from marine to non-marine sedimentation. Specifically, in the Spanish Pyrenees the last lagoonal intercalations in the Tremp Fm (-Ma42) are followed by brackish and non-marine sediments which extend across the K/T boundary. In the French Pyrenees this transition is significantly later with intervening orbitoid beds (Ma85?-Ma92?) between the last rudists and the start of non-marine deposition (Ma92?-Ma100?) and then Palaeocene dolomite. This implies a slight transgression before the final regressive phase.

The Balkans were also part of the northern margin. In this area there is no evidence for terminal Maastrichtian or lowermost Palaeocene strata but I have little information about this. I suggest that rudist deposition did not continue past the early Maastrichtian (Ma28) in the eastern Serbian-Bulgarian area (and there may be Maastrichtian non-marine strata covering the rudist deposits at Garlo in Bulgaria). Some localities in the Inner Dinarides were perhaps unaffected by the regression until later (Ma50?). They are overlain by Tertiary Flysch.

From the southern margin I have data from the Periadriatic, a region which proabably formed a promentory attached to the southern margin, and from sequences which were

In the Caribbean, some authors (such as Kaufmann, in Hut *et al.*, 1987) see the continuation of the rudist facies across the K/T boundary, though without the rudists themselves.

In figure 6/4 the lithological columns of figure 6/2 are alligned to enable the reader to compare the timing of sealevel changes between the different areas. This shows that though deposition of an outer platform rudist facies is terminated by a minor trangression followed by the major regression in all these cases, it is not at the same time in all places. This effect is almost certainly due to local variations rates of subsidence/uplift.

Figure 6/5 attempts to show the overall effect of the Maastrichtian regression, in terms of the relative proportions of marine/non-marine/pelagic strata/non-deposition through time for these rudist-bearing sequences. Each zone is plotted as one unit and subdivided according to the strength of the palaeogeographic affinities of the sequences (which follows the numbering system). This shows that the main effects of the regression occur from the middle of the Maastrichtian (Ma40) onwards. The regression probably starts around the middle of the Campanian (Ma50) and most probably reaches its climax at the K/T boundary (although this can not be proven conclusively from these data).

There is a certain amount of agreement between these findings and that displayed in the Haq *et al.*, 1988. This is based upon data from Aquitaine (in the Tethyan realm), central Texas (Caribbean Tethys), and sequences in Belgium & Holland (Boreal realm). The eustacy curve in that work also shows a major regressive trend starting in the middle of the Campanian and continuing through the Palaeocene. There are three shorter regressive phases superimposed upon this, one at the Campanian/Maastrichtian boundary, a slightly larger one in the middle of the Maastrichtian and the largest centered at the K/T boundary. Using the data in figure 6/4, I cannot distinguish these as separated events.

6.5 Palaeobiogeographic distribution and extent of endemism

Figure 6/5 shows the palaeobiogeographic distribution for the rudist bivalves and larger benthic foraminifera for the late Campanian-Maastrichtian. The diagram is at generic level because the taxonomy at species level is insufficiently well established. In European-

deposited to the south of this and which I have grouped together in the N. African region. The situation in the Periadriatic area is complex. On the Dinaric Platform the main rudist-bearing, outer margin facies was brought to an end with a regression. After a short interval of time there was a slight transgression and a very shallow water, inner platform facies was deposited middle Maastrichtian times (Ma20?-51 at Dolenja Vas, Ma20?-40? on Brač island). On the Adriatic Platform the regression was at approximately the same time (Ca95 on M. Jouf and M. Nanos) though a transition to orbitoid limestones on sections adjacent to the main M.Jouf sequence demonstrates a short-lived transgression before the main regressive phase. The platforms then evidently began to break up (due to the Dinaric phase of the Alpine orogeney) with the production of talus and deposition of the basinal facies of pelagic marl followed by flysch (this break-up seems to have been at various intervals from the latest Campanian to Early Palaeocene - see Pirini Radrizzani *et al.*,1986).

On the Apulian platform there seems to have been one final regression which marked the end of carbonate deposition and no further sedimentation until the Mio-Pliocene. At Gargano the regressive phase is attested to by the transition to slope/pelagic carbonate at the very top of the sequence.

Less is known about the rudist facies in the African region but in western Sicily the regression caused carbonate deposition to cease at around the C/M boundary (Ca80 or Ma10) and not to restart until the Early Eocene. At Quatretonda, S. Spain a rudist-free orbitoid limestone intervenes (Ma30-Ma60) before the final lacuna. At other areas in eastern Africa, such as in Tunisia, rudist limestones are overlain by pelagic sediments.

The situation in the Arabian area is dominated by the obduction of the Oman ophiolite and a consequent transgression onto the loaded crust in the Campanian, the regression being diachronous (Ca50?-Ma20?). However, the major regression in the Maastrichtian still affects the area despite the local subsidence. In the sequences in the Oman Mountains and those on the sides of the Aruma Basin (in central Saudi Arabia and southern Oman) an orbitoid limestone intervenes between the last main rudist beds and the lacuna. They are overlain by Paleocene pelagic deposits.

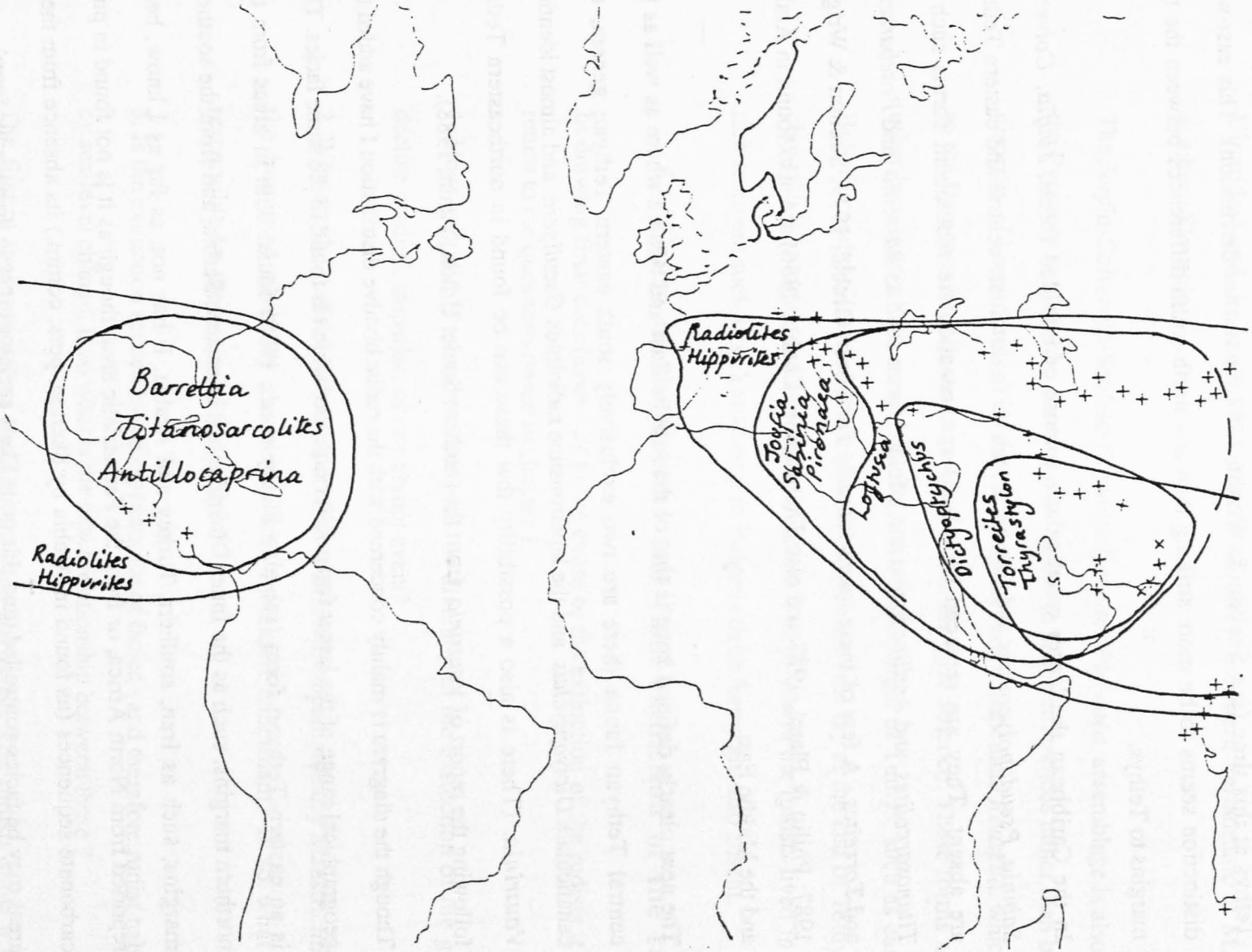


Figure 6/6. Palaeobiogeographic distribution of rudists and certain larger foraminifera for the late Campanian and Maastrichtian

African-Asian Tethys there is a progressive enrichment of forms going east including the introduction of some Caribbean forms in Arabia and the Middle East. This is in line with all reconstructions of the palaeocurrent which almost certainly flowed from east to west through Tethys at this time (see Skelton & Wright, 1987 for further discussion). This east-west distinction seems to be more striking then any north-south differences between the two margins to Tethys.

In the Caribbean the larger canaliculate, spinose or infolded forms, *Joufia, Colveria, Sabinia, Pseudopolyconites* and *Pironaea* , which so dominate central and eastern Tethys, are absent. They are replaced by other large, canaliculate recumbent forms such as *Titanosarcolites* and *Antillocaprina* and infolded forms such as *Barrettia* and *Praebarrettia* and *Torreites* . A few of these forms (notably *Torreites* , Grubić, 1979; Skelton & Wright, 1987; Philip & Platel, 1987 and also *Thyrastylon,* Chubb, 1956) are also found in Arabia and the Middle East.

The next clearly defined zone is that of the Middle East and Arabia where as well as the central Tethyan fauna there are two exclusively south-eastern Tethyan genera, the canaliculate *Dictyoptychus* and the lapeirousiine radiolitids *Osculigera* and almost identical *Vautrinia.* (There is also a possibility that these can be found in northeastern Tethys following the report of *Vautrinia* from the southern Soviet Union, Yanin, 1988).

Though the diagram is mainly concerned with the rudist bivalve distribution I have added the geographical range of the larger foraminifer *Loftusia* which is found in the same facies. This is an eastern Tethyan form (see also Fleury *et al.*, 1990) found both in areas from the northern margins, such as the Inner Dinarides and in eastern Serbia, and from the southern margins, such as Iran, southern Turkey and Arabia. It has not, as far as I know, been reported from North Africa, or from the Periadriatic area, though as it is not found in pure carbonate sequences (as found in Arabia by Skelton, pers. comm.) its absence from these areas may be facies controlled (and this quite likely seeing as it is an arenaceous form).

There are some forms which seem to have very narrow distribution in areas of central Tethys (though in areas with quite different facies), but which are poorly known and may in time be

found elsewhere. These include the three *Radiolitella* - like canaliculate forms *Kuehnia* (northern Periadriatic in southern Slovenia & Inner Dinarides) *Pseudokuehnia* (southern Periadriatic at Salento) and *Fundinia* (southern Periadriatic on Brač island & Inner Dinarides) and the acellular radiolitid *Katzeria* (northern Periadriatic at M. Jouf and in southern Slovenia).

The *Joufia-Colveraia-Sabinia-Pseudopolyconites-Pironaea* assemblage is also absent from the Pyrenees but here the absence may be due to facies differences rather than barriers to the dispersal of larval forms. The smaller relatively rare, canaliculate *Rouselia,* which is endemic to the Pyrenees hardly seems to compensate for their absence. These forms are present at other localities which were part of the northern margin of Tethys, such as eastern Serbia-Bulgaria and the Internal Dinarides. The Pyrenean area lay at the end of Tethys and where clay-rich lithologies accumulated. In eastern Tethys where the rudists lived in such a clay-rich sediment such as at Yaroslavtzi in Bulgaria these forms are also absent.

6.6 Cause of the decline and final extinction of the rudists

In drawing final conclusions as to the cause of the extinction of the rudists it is helpful to return to the questions posed in chapter 1.

1. How long did it take from the peak of diversity to the extinction of the group. Is this decline gradual, stepwise, or one abrupt event?

2. Why are the rudists at their most diverse in late Campanian/early Maastrichtian times - is the increased diversity associated with increased endemism? If so what factors are responsible for the increased endemism ?

3. Is the extinction related to a disappearance of facies - and therefore rudist habitat - caused by sea-level change. If so what is the exact relationship between these ?

The first of these questions has already been answered. The rudists show a gradual, and generally constant, decline. At the specific level the decline extends from the diversity maximum at the Boreal Campanian/Maastrichtian boundary almost to the end of the

Maastrichtian but leaving a very few surviving Tertiary forms.

The cause of the decline is probably related to the reasons for the prior increase in diversity. I do not think that increased endemism is the main cause, though it is hard to comment upon the extent of endemism versus time through the late Cretaceous and it may indeed have been slightly greater in late Campanian-Maastrichtian times than it was before.

In my opinion far more important than palaeobiogeographic differences were the sea-level changes and the effect that these had upon the growth and retreat of the carbonate platforms. In periods of slight, but steady sealevel rise, carbonate platforms build up and out and may change their topography from a ramp into a platform (see Swinburne & Noacco, in press, in the appendix and note particularly their figure 9). In the Late Cretaceous there were two cycles of growth of these platforms. The first cycle terminated at the end of the Cenomanian with a sharp regression which exposed a substantial area of the platforms, and was followed by a rapid transgression which caused their drowning (see Philip, 1982 and references therein). Following this transgression, the platforms began to build out again in a similar manner until their growth came to an end by the regression in the Maastrichtian Period.

Thus there are two intervals when the platforms are at their maximum extent in the Late Cretaceous, at the end of the Cenomanian and in the late Campanian-early Maastrichtian. At these times rudists had the maximum diversity of habitats ranging from the slope edge, outer margin, inner margin to middle and inner shelf areas (see also Accordi *et al,* 1988 & Cestari & Sirna, 1987, and references therein for further descriptions of these habitats). In the fast-moving shallow waters large canaliculate forms flourished. It is to a large extent the extinction of these forms which gave rise to such a dramatic drop in diversity at the Cenomanian/Turonian boundary (see figure 1/4 and also Masse & Philip, 1986).

The Maastrichtian regression was an event of far greater magnitude leading to eventual total loss of rudist habitat. Interestingly some of the same features can be observed as in the Cenomanian/Turonian event. For instance, the outer and middle shelf forms are similarly the first to be extinguished as their habitats are removed, leaving a few temporary survivors, which are small forms, mostly radiolitids, in inner platform facies. Different areas had their

own topographies and subsidence rates so the main effect of the regression was at slightly different times. Yet overall the regression lead to a gradual loss of rudist habitat, beginning at around Ca70, and continuing througout the Maastrichtian.

Significantly the graph of disappearance of marine facies with time (fig. 6/4) is slightly offset from the graphs of rudist diversity (fig. 6/3). This feature results from the presence, in many sequences, of a transgressive unit of platform carbonate which contains either no rudists at all, or at any rate very few. This clearly demonstrates that the gradual extinction of the rudists is not simply due to non-exposure of terminal Maastrichtian strata in which rudists would have been present, but that such rudists no longer existed because they had no where suitable to live.

Bibliography

Accordi, G., Carbone, F. & Sirna, G., 1987. Some affinities between the Ionian islands and the Apulian Upper Cretaceous Rudist facies. *Memorie della Società geologica Italiana*, 40, 163-175.

Accordi, G., Carbone, F. Catalano, G., Reali, S. & Sirna, G., 1988. The rudist assemblage of Maiella mt. (Central Italy): Palaeobiogeographic implications. Abstract in: M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988.

Accordi, G., Carbone, F., Sirna, G., 1982. Relationships among tectonic settings, substratum and benthonic communites in the Upper Cretaceous of northeastern Matese (Molise, Italy). *Geologica Romana*, 21, 755-793, 5 pl. excl.

Al-Aasm, I. & Veizer, J., 1986a. Diagenetic stabilization of aragonite and low-Mg calcite, I. Trace elements in rudists. *Journal of Sedimentary Petrology*, 56 (1), 138-152.

Al-Aasm, I. & Veizer, J., 1986b. Diagenetic stabilization of aragonite and low-Mg calcite, II. Stable isotopes in rudists. *Journal of Sedimentary Petrology*, 56 (6), 763-770.

Amico, S., 1978. Recherches sur la structure du test des Radiolitidae. Travaux du Laboratoire de Géologie Historique et de Paléontologie. Université de Provence. Marseille. no. 8, 131pp.

Berggren, W.A., Kent, D.V. & Flynn, J.J., 1985. Jurassic to Paleogene: Part I. Cretaceous geochronology and chronostratigraphy. In: *N.J. Snelling (ed.), The chronology of the Geological Record.* Geological Society of London, Memoir 10, 141-195.

Bernet-Rollande, M.-C. & Philip, J., 1981. Sur la découverte d'un récif à Caprinidés (rudistes) dans le Sénonien du Djebel Serraguia (Tunisie centre-occidentale). *Comptes rendues de Académie de Science. Paris (Série II)*, 292, 417-422.

Bignot, G., 1972. Recherches stratigraphiques sur les calcaires du Crétacé supérieur et de l'Éocene d'Istrie et des régions voisines. Essai de révision du Liburnien. Travaux du Lab. Micropal., 2, 1-353, 50 pl.. Abstract in: *Compte rendu sommaire de la Société géologique de France*, 6, p 249.

Bignot, G. & Cadet, J.P., 1972. Sur la stratigraphie des couches de passage du Crétacé au Tertiaire. Le Liburnien de Dalmatie et d'Hercegovine méridionales (Yougoslavie). *Compte rendu sommaire de la Société géologique de France*, 7.

Bilotte, M., 1985. Le Crétacé Supérieur des plates-formes Est Pyrénéennes. Strata: Actes du laboratoire de géologie sédimentaire et paléontologie de l'université Paul-Sabatier, Toulouse. Série 2: Mémoire 5 .

Birkelund, T., Hancock, J.M., Hart, M.B., Rawson, P.F., Remane, J., Robaszynski, F., Schmid, F. & Surlyk, F., 1984. Cretaceous stage boundaries - Proposals. *Bulletin of the geological Society of Denmark*, 33, 3-20.

Böhm, G., 1897. Beitrag zur Gliederung der Kreide in den Venetianer Alpen. *Zeitschrift der deutschen geologischen Gesellschaft*, 49, 160-181.

Böhm, G., 1898. Zur Kenntniss der Gattung *Joufia* . *Zeitschrift der deutschen geologischen Gesellschaft*, 50, 591-592.

Borgomano, J. & Philip. J., 1987. The rudist carbonate build-ups and the gravitary carbonates of the Gargano-Apulian margin (Southern Italy, Upper Senonian). *Memorie della Società geologica Italiana*, 40, 125-132.

Brand, U. & Veizer, J., 1980. Chemical diagenesis of a multicomponent carbonate system - 1: Trace elements. *Journal of Sedimentary Petrology*, 50 (4), 1219-1236.

Brand, U. & Veizer, J., 1981. Chemical diagenesis of a multicomponent carbonate system - 2: Stable isotopes. *Journal of Sedimentary Petrology*, 51 (3), 987-997.

Burke, W.H., Denison, R.E., Hetherington, E.A., Koepnick, R.B., Nelson, H.F. & Otto, J.B., 1982. Variation of seawater 87Sr/86Sr throughout Phanerozoic time. *Geology*, 10, 516-519.

Buser, S., 1987. Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian basin (NW Yugoslavia). *Memorie della Società geologica Italiana*, 40, 313-320, 2 pl.

Busulini, A., Dieni, I. & Massari, F., 1984. Nouvelles données sur le Crétacé Supérieur de la Sardaigne Orientale. *Cretaceous Research*, 5, 243-258.

Camoin, G., 1983. Plates-formes carbonatées et récifs à rudistes du Crétacé de Sicile. Thèse doctorat de l'Université de Provence. Travaux du Laboratoire de Géologie historique et de Paleontologie, Université de Provence, Marseille, no. 13, 24 pl., 2 encl. excl.

Camoin, G., 1985. Relations entre volcanisme sous-marin, récifs à Rudistes campaniens et irrégularités de la sédimentation paléogène dans le Sud-Est de la Sicile (Italie). *Comptes rendues de Académie de Science. Paris (Série II)*, 300, 619-624.

Camoin, G., Philip, J. & Bernet-Rollande, M.-C., 1983. Stratigraphie et paléobiogeographie des récifs à Rudistes du Sénonien supérieur du Sud-Est de la Sicile. Relations avec le volcanisme sous-marin. *Comptes rendues de Académie de Science. Paris (Série II)*, 296, 1093-1096.

Campobasso, V., 1972. Rudiste del Cretaceo superiore delle Murge sud-orientali. *Bollettino della Società di naturalisti i Napoli*, 81, 433-460.

Campobasso, V & Morolla, M., 1975. Osservazioni su *Joufia reticulata* Boehm, 1897 (Radiolitidae). *Bollettino della Società di naturalisti i Napoli*, 84, 405-439.

Cati, A., Sartorio, D. & Venturini, S., 1987. Carbonate platforms in the subsurface of the northern Adriatic area. *Memorie della Società geologica Italiana*, 40, 295-308, 2 encl., excl.

Caus, E. & Cornella, A., 1985. Macroforaminifères du Crétacé supérieur du bassin sud-pyrénéen. *Géologie Méditerranéenne*, 10 (1983) (3-4), 137-142.

Caus, E., Cornella, A., Gallemi, J., Gili, E., Martinez, R. & Pons, J.M., 1981. *Field Guide: Excursions to Coniacian-Maastrichtian of South Central Pyrenees. Universidad Autonoma de Barcelona, Publicaciones de Geologia*, No. 13.

Caus, E. & Hottinger, L., 1986. Particularidades de la fauna (macroforaminíferos) del Cretácico superior pirenaico. *Paleontologia i Evolucío*, 20, 115-123.

Cavallin, A. & Pirini Radrizzani, C., 1983. Evoluzione del settore settentrionale della piattaforma carbonatica adriatica. *Rivista italiana di Paleontologia e Stratigrafia*, 89 (2), 223-242.

Cavelier, C., Platel, J.P., Roger, J., Berthiaux, A. & Robelin, C., 1985. Stratigraphie et histoire géologique du Dhofar (Sultanat d'Oman) depuis la transgression Crétacé. *Principaux résultats scientifiques et techniques du Bureau de Recherche Géologique et Minière RS 1976*, 50-52.

Cestari, R. & Sirna, G., 1987. Rudist fauna in the Maastrichtian deposits of southern Salento (Southern Italy). *Memorie della Società geologica Italiana*, 40, 133-147, 7 pl. excl.

Cestari, R. & Sirna, G., 1988. Rudist communities in the Senonian and Maastrichtian sequences in the Simbruini, Ernici and Ausoni mts. (Central Apennines, Central Italy). Abstract in: *M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988* , p. 4.

Channell, J.E.T., D'Argenio, B. & Horvath, F., 1979. Adria, the African promontory, in Mesozoic Mediterranean palaeogeography. *Earth Science Reviews*, 15, 213-292.

Christensen, W.K., 1975. Upper Cretaceous belemnites from the Kristianstad area in Scania. *Fossils and Strata no. 7.*

Christensen, W.K., 1988. Upper Cretaceous belemnites of Europe: state of the art. In: *M. Streel & M.J.M. Bless (eds.), The chalk district of the Euregio Meuse-Rhine*, 5-16.

Chubb, L.J., 1956a. Rudist assemblages of the Antillean Upper Cretaceous. *Bulletin of American Paleontology*, 37, 1-23.

Chubb, L.J., 1956b. Thyrastylon, a new rudist genus from the Upper Cretaceous of Guatemala, the Antilles, and Persia, with a discussion of the function of rudist oscules and pillars. *Palaeontographica Americana*, 4 (27), 31-48.

Civitelli, G. & Mariotti, G., 1975. Paleontological and sedimentological characteristics of the Senonian of Pietrasecca (Carseolani Mountains, Central Apennines). *Geologica Romana*, 14, 87-124, 3 pl. excl.

Cousin, M., 1963. Contribution à l'étude géologique des Préalpes carniques orientales (Alpes méridionales, province d'Udine, Italie). *Bullétin de la Société géologique de France*, 5 (7), 809-820.

Cousin, M. & Fourcade, E., 1982. Les faciès Crétacés de la plate-forme Frioulano-karstique et leur environnement paléogéographique (Alpes Méridionales et Dinarides). *Cretaceous Research*, 3, 113-123.

Cox, L.R., 1960. Two new radiolitids (rudistid Lamellibranchia) from the Upper Cretaceous of Turkey. *Bulletin of the British Museum (Natural History), Geology*, 4 (9), 427-432, 2 pl. excl.

Czabalay, L., 1988. Correlation des coenozones à rudistes du Crétacé (Hongrie) dans la région de Tethys. Abstract in: *M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988* , p. 6.

Dechaseux, C., Perkins, B.F. & Coogan, A.H., 1969. Superfamily Hippuritacea Gray, 1848. In: R.C. Moore (ed.), Treatise on Invertebrate Paleontology, Part N, vol. 2, Mollusca 6, Bivalvia, , N749-N817, Geological Society of America and University of Kansas Press, Lawrence, Kansas.

Delaney, M.L., 1983. Foraminiferal trace elements: uptake, diagenesis and 100 M.y. paleochemical history. *Thesis, Massachusetts Institute of Technology.*

DePaolo, D.J., 1986. Detailed record of the Neogene Sr isotopic evolution of seawater from DSDP site 590B. *Geology*, 14, 103-106.

DePaolo, D.J. & Ingram, B.L., 1985. High resolution stratigraphy with strontium isotopes. *Science*, 227, 938-941.

Douville, H., 1904. Mollusques fossiles. In: *J. De Morgan (ed.), Mission scientifique en Perse, Tome 3ème, Partie 4 - Paléontologie.* 191-380, Ernest Leroux, Paris.

Douvillé, H., 1910. Études sur les rudistes. Rudistes de Sicile, d'Algérie, d'Égypte, du Liban et de la Perse. *Mémoires de la société géologique de France*, 41, 83pp, 7 pl. excl.

Drobne, K., 1979. Excursion P, Postojna - Senonian (Keramosphaerina tergestina STACHE). In: *Proceedings of the 16th European Micropaleontological Colloquium*, , 243-246, Ljubljana.

Drobne, K., Ogorelec, B., Pleničar, M., Barattolo, F., Turnsek, D. & Zucchi-Stolfi, M., 1987. The Dolenja Vas section, a transition from Cretaceous to Paleocene in the NW Dinarides, Yugoslavia. *Memorie della Società geologica Italiana*, 40, 73-84.

Drobne, K., Ogorelec, B., Pleničar, M., Zucchi-Stolfa, M.L., Turnšek, D., 1988. Maastrichtian, Danian and Thanetian beds in Dolenja Vas (NW Dinarides, Yugoslavia). Mikrofacies, foraminifers, rudists and corals. *Academia scientiarum et artium Slovenica, Classis IV: historia naturalis. Dissertationes*, 29, 1-224, 35 pl. excl., Ljubljana.

El Asa'ad, G.M.A., 1984. The paleobiogeographic distribution of the Late Cretaceous fauna of Arabia and surrounding areas. *Arab Gulf Journal of scientific Research*, 2 (1), 105-121.

Elderfield, H., 1986. Strontium isotope stratigraphy. *Palaeogeography, Palaeoclimatology and Palaeoecology*, 57, 71-90.

Emberger, J., 1954. Présence d'*Agria marticensis* D'Orb et de *Praeradiolites pulchellus* Vidal dans les terrains crétacés du Hodna (Algérie) . *Comptes rendus de l'academie des sciences*, , 48-50.

Fleury, J.J., 1970. Le Senonien et l'Éocène à microorganismes benthoniques du Klokowa (zone du Gavrovo, Akarnanie, Grèce continentale). *Revue de Micropaléontologie*, 13 (1), 30-44, Paris.

Fleury, J.J., 1973. Sur l'âge Crétacé terminal (Maastrichtien) des couches a *Rhapydionina liburnica* (Stache) de la zone de Gavrovo-Tripoliza (Grèce continentale et Péloponnèse). *Compte rendu sommaire de la Société géologique de France*, fasc. 4, 125-127, Paris.

Fleury, J.J., 1979. Le genre *Murciella* (Foraminière, *Rhapydionininae*) dans le Crétacé supérieur de Grèce (zone de Gavrovo-Tripoliza). *Geobios*, 12 (2), 149-185, 5 pl. excl., Lyon.

Fleury, J.J., 1980. Les zones de Gavrovo-Tripoliza et du Pinde-Olonos (Grèce continentale et Péloponnèse du Nord). Evolution d'une plate-forme et d'un bassin dans leur cadre alpin. *Société geologique du Nord*, no. 4 (2 vol., 651), 651pp.

Fleury, J.J., Mavrikas, G. & Baudin, F., 1990. Paléobiogeographie du genre *Loftusia* , foraminifère du Crétacé terminal de la Téthys. *Bullétin de la Société géologique de France. 8ème Série*, 6 (3).

Freneix, S. & Sornay, J., 1974. *Artegesia* , genre nouveau de Monopleuridae du Maestrichtian de Royan (Charente-Maritime). *Bullétin du Muséum National d'Histoire Naturelle. Paris. 3ème série*, 215 (1), 97-111.

Gallemi, J., Martinez, R. & Pons, J.M., 1983. Coniacian-Maastrichtian of the Tremp area (South Central Pyrenees). *Newsletter in Stratigraphy*, 12 (1), 1-17.

Gili, E., Masse, J.-P. & Skelton, P.W., 1990. Did rudists build reefs? Abstract for *2nd International Rudist Conference, held in Rome, Oct. 1990.*

Goldstein, S.J. & Jacobsen, S.B., 1987. The Nd and Sr isotopic sytematics of river-water dissolved material: implications for the sources of Nd and Sr in seawater.

Chemical Geology (Isotope Geoscience Section), 66, 245-272.

Goldstein, S.J. & Jacobsen, S.B., 1988. Nd and Sr isotopic sytematics of river water suspended material: implications for crustal evolution. *Earth and Planetary Science Letters*, 87, 249-265.

Graham, D.W., Bender, M.L., Williams, D.F. & Keigwin, L.D. Jr., 1982. Strontium-calcium ratios in Cenozoic planktonic foraminifera. *Geochimica et Cosmochimica Acta*, 46, 1281-1292.

Grubić. A., 1975. Nouvelle consideration de certains hippuritides déjà décrits existant en Iran et en Yugoslavie. *Annales Géologiques de la Péninsule Balkanique*, 39, 143-146, 3 pl. excl.

Grubić. A., 1979. Torreites milovanovići sp. nov. from Oman, T. conzi sp. nov. and T. chubbi sp. nov. from Jamaica, a new description of the genus Torreites Palmer, and a refferrence to the significance of its palaeogeographic distribution. *Institut de Recherches Geologiques et Geophysiques, Vjesnik, Série A*, 37, 81-95, 8 figs. incl., 2 pl. excl.

Håkansson, E. & Hansen, J.M., 1979. Guide to Maastrichtian and Danian boundary strata in Jylland. In: *Birkelund, T & Bromley, R.G (eds.). Cretaceous-Tertiary boundary events. Symposium. 1. The Maastrichtian and Danian of Denmark.* 171-189

Hallam, A., 1987. End-Cretaceous mass extinction event: argument for terrestrial causation. *Science*, 238, 1237-1242.

Haq, B.U., Hardenbol, J. & Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: *Sea-level changes - an integrated approach. SEPM Special Publication No. 42.*

Harland, W.B., Smith, A.G., Wilcock, B., (eds.) 1964. The Phanerozoic timescale. A symposium dedicated to Professor Arthur Holmes. *Quarterly Journal of the Geological Society of London. Supplement.* 458pp.

Harland, W.B., Cox, A.V., Llewellyn, P. G., Pickton, C.A.G., Smith, A.G. & Walters, 1982. *A geologic time scale*, 131pp, Cambridge University Press, New York.

Hess, J., Bender, M.L. & Schilling, J.-G., 1986. Evolution of the ratio of strontium-87 to strontium-86 in seawater from Cretaceous to Present. *Science*, 231, 979-984.

Höfling, R., 1988. Rudist buildups and their associated palaeoenvironments in the northern Calcareous Alps. Abstract in: *M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988*, p. 10.

Hottinger, L. & Rosell, J., 1983. El Cretacico Superior del Montsec. *XIII Coloquio europeo de micropaleontologia, España, 1973*, 8, 73-112.

Hut, P., Alvarez, W., Elder, W.P., Hansen, T., Kauffman, E.G., Keller, G, Shoemaker, E.M. & Weissman, P.R., 1987. Comet showers as a cause of mass extinctions. *Nature*, 329, 118-126.

Javoy, M. & Courtillot, V., 1989. Intense acidic volcanism at the Cretaceous-Tertiary boundary. *Earth and Planetary Science Letters*, 94, 409-416.

Jelaska, V., Ogorelec, B. & Ercegovac, M., 1983. The Upper Cretaceous depositional environments of the carbonate platform on the island of Brač. In: *Babić, L.J. & Jelaska, V. (eds.), Contributions to sedimentology of some carbonate and clastic units of the coastal Dinarides. Excursion guide book, 4th I.A.S. regional meeting, Split, 1983*, 99-124,

Zagreb.

Jeletsky, 1951. Die Stratigraphie und Belemnitenfauna des Obercampan und Maastricht Westfalens, Nord-westdeutschlands und Dänemarks sowie enige allgemeine Gliederungs-Probleme der jüngeren borealen Oberkreide Eurasiens. *Beihefte zum Geologischen Jahrbuch*, 1, 142 pp.

Johnson, C.C. & Kaufmann, E.G., 1990. Originations, radiations and extinctions of Cretaceous rudistid bivalve species in the Caribbean province. In: *E.G. Kauffman & O.H. Walliser (eds.), Extinction events in earth history, Lecture notes in Earth Sciences*, 30, 305-324,Springer Verlag, Berlin.

Jones, D.S., Mueller, P.A., Bryan, J.R., Dobson, J.P., Channell, J.E.T., Zachos, J.C., Arthur, M.A., 1987. Biotic, geochemical, and paleomagnetic changes across the Cretaceous/Tertiary boundary at Braggs, Alabama. *Geology*, 15, 311-315.

Karacabey, N., 1968. Sur les nouvelles espèces de *Vaccinites* Fisher et *Yvaniella* Milovanović trouvées dans la région d'Amasya. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 71, 29-41.

Karacabey, N., 1969. Sur une éspèce de *Joufia* Boehm prélevée dans la partie orientale de la Turquie. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 73, 133-139.

Karacabey, N., 1970. Quelques espèces de *Vaccinites* et de *Pironaea* de l'Anatolie orientale. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 74, 52-58, 4 pl. excl.

Karacabey-Öztemür, N., 1974. Sur une nouvelle espèce de *Colveraia* Klinghardt et une nouvelle sous-espèce de *Joufia* Boehm en Turquie. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 82, 78-85.

Karacabey-Öztemür, N., 1976. Un nouveau genre de Radiolitidae: *Darandeella* n. gen.. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 86 .

Karacabey-Öztemür, N., 1980. Two new genera of Radiolitidae (*Balabania* n. gen., *Kurtinia*, n. gen.) from Turkey. *Turkiye Jeloi Kurum. Bülteni C*, 23, 79-86 (Subat).

Karacabey-Öztemür, N., 1981a. Description of two new species of the genus *Dictyoptychus* found in Turkey. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 92, 35-39.

Karacabey-Öztemür, N., 1981b. Three new species of the genus *Miseia* and proposal of a new subfamily of Radiolitidae. *Bulletin of the Mineral Research and Exploration Institute of Turkey*, 92, 40-76, 5 pl. excl.

Kauffman, E.G., 1988. The dynamics of marine stepwise mass extinction. *Revista Española de Paleontologia. no. Extraordinario*, 57-71.

Kennedy, W.J., 1986. Campanian and Maastrichtian ammonites from northern Aquitaine, France. Palaeontological Association special publication, 36, 145pp, 23 pls excl.

Kennedy, W.J., 1989. Thoughts on the evolution and extinction of Cretaceous ammonites. *Proceedings of the Geological Association*, 100 (3), 251-79.

Klinghardt, F., 1921a. Die Rudisten. Teil I: Neue Rudistenfauna aus dem Maastrichtien von Maniago in Friaul, dazu stratigraphischer Anhang. *Archiv für Biontologie*, 5 (1), 1-68.

Klinghardt, F., 1921b. Die Rudisten. Teil IV, Atlas, Selbstverlag, Berlin, Greifswald.

Koepnick, R.B., Burke, W.H., Denison, R.E., Hetherington, E.A.,

Nelson, H.F., Otto, J.B. & Waite, L.E., 1985. Construction of the seawater 87Sr/86Sr curve for the Cenozoic and Cretaceous: supporting data. *Chemical Geology (Isotope Geoscience Section)*, 58, 55-81.

Kühn, O, 1933. Stratigraphie und Paläogeographie der Rudisten. I. Rudistenfauna und Kreideentwicklung in Anatolien. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. Abteilung B. Geologie. Paläontologie*, 90, 267-316.

Laviano, A., 1984. Preliminary observations on the Upper Cretaceous coral-rudist facies of Ostuni (southeastern Murge, Apulia). *Rivista italiana di Paleontologia e Stratigrafia*, 90 (2), 177-204.

Laviano, A., 1985. Paleontological descriptions of some rudists from the Upper Cretaceous of Ostuni (BR-Italy). *Rivista italiana di Paleontologia e Stratigrafia*, 91 (3), 321-356.

Liebau, A., 1983. El Maastrichtense lagunar (Garumniense) de Isona. *XIII Coloquio europeo de micropaleontologia, España, 1973*, 87-112.

Liebau, A., 1984. Ökobathymetrie und Paläogeographie des Maastrichtiums des Beckens von Tremp (Südpyrenäen). In: H.P. Luterbacher (ed.), Paläontologische Kursbücher, Band 2: Paläobathymetrie, , 185-225, Paläontologische Gesellschaft Sebstverlag, München.

Livermore, R.A. & Smith, A.G., 1985. Some boundary conditions for the evolution of the Mediterranean region. In: *D.J. Stanley, F.-C. Wetzel (eds.), The geological evolution of the Mediterranean Basin*, chapter 5, 83-98. Springer Verlag, New York.

Lupu, D., 1971. Rudistes Maestrichtiens de Brezoi-Carpates méridionales centrales (collection de Popescu-Voitesti). *Dari de seama ale sedintelor*, 57, 21-27. (In Romanian).

Lupu, D., 1976. Un nouveau radiolitidé: *Bystrickya andrusovi* n. gen. nov. sp. du Sénonien Supérieur de la haute vallée du Hron (Horehronie, Carpates Slovaques). *Geologicky Zbornik - Geologica Carpathica*, 27 (1), 35-43. (Bratislava).

Lupu, D., 1984. Biostratigraphie und Faziesentwicklungen der Mittel- und Oberkreide des Apuseni-Gebirges. *Schriftenreihe der Erdwissenschaftlichen Kommissionen*, 7, 15-25, Österreichische Akademie der Wissenschaften.

Lupu, D. & Lupu, M., 1981. Biostratigraphische und Fazielle Merkmale der "Gosauformation" im Apuseni Gebirge. *Presentation at the 12th Congress of the Carpatho-Balkan Geological Association, 8-13th Sept., 1981, Bucharest, Romania.*

MacDougall, J.D., 1988. Seawater strontium isotopes, acid rain, and the Cretaceous-Tertiary boundary. *Science*, 239, 485-487.

Mariotti, G., 1982. Alcune facies a rudiste dei Monti Carseolani: descrizione e correlazione dal bordo occidentale all'interno della piattaforma Laziale-Abruzzese. *Geologica Romana*, 21, 885-902.

Masse, J.-P. & Philip, J., 1974. Définition, position systématique, répartition stratigraphique et évolution du genre Agriopleura Kühn, (Rudiste). *Géologie méditerranéenne*, 1 (2), 53-62.

Masse, J.-P. & Philip, J., 1986. L'évolution des rudistes au regard des principaux événements géologiques du Crétacé.*Géologie Mediterraneenne*, 10 (2), 437-456.

Matteucci, R., Schiavinotto, F. & Sirna, G., 1982. Palaeoenvironmental significance of Maastrichtian biological communities in the Pachino area (Sicily) and preliminary data on their distribution in the Mediterranean Upper Cretaceous. In: *E.M. Gallitelli (ed.), Proceedings of the First International Meeting on "Palaeontology, Essential of Historical Geology", held in Venice, Fondazione Giorgio Cini, 2-4 June, 1981*, 77-95,

S.T.E.M. Mucchi, Modena.

Mckenzie, J., Hodell, D.A., Mueller, P.A. & Mueller, D.W., 1988. Application of strontium isotope to late Miocene-early Pliocene stratigraphy. *Geology*, 16, 1022-1025.

Milovanović, B., 1932. Contribution à la connaissance des rudistes de la Serbie. *Annales Géologiques de la Péninsule Balkanique*, 11 (1), 71-73, 8 pl. 1 fig. excl., *French résumé published in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 8-29 .

Milovanović, B., 1934a. Les rudistes de la Yougoslavie I. Serbie orientale, occidentale et Ancienne Raška. *Annales Géologiques de la Péninsule Balkanique*, 12 (1), 178, *French résumé published in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 33-39 .

Milovanović, B., 1934b. Nouvelles observations sur le genre Pironaea Meneghini. *Bullétin du Service Géologique et Géophysique de la Royaume de Yougoslavie*, 3 (2), *French résumé published in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 43-61 .

Milovanović, B., 1935a. Les rudistes de la Yugoslavie II. *Annales Géologiques de la Péninsule Balkanique*, 12 (2),, 5 pl. excl., *French résumé published in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 64-81.

Milovanović, B., 1935b. Sur les rudistes du Maëstrichtien dans la partie orientale de la Péninsule Balkanique. *Geologica Balkanica*, 1 (3), 127-136, *Reprinted in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 131-141.

Milovanović, B., 1937. Les nouveaux rudistes de la Serbie. *Bulletin de l'Académie Royale Serbe des Sciences mathématiques et naturelles. B. Sciences Naturelles*, 3, ,, *Reprinted in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 165-206.

Milovanović, B., 1938. Anatomie comparée et relations phylogénétiques de Lapeirouseiinae. *Bulletin de l'Académie Royale Serbe des Sciences mathématiques et naturelles. B. Sciences Naturelles*, 4, *Reprinted in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 285-358.

Milovanović, B., 1960. Stratigraphie du Sénonien dans les Dinarides yougoslaves d'après les rudistes. *Bullétin de la Société géologique de France*, 7 (2), 366-375 *Reprinted in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 455-464 .

Milovanović, B. & Grubić, A., 1971. Le Senonien supérieur à rudistes des Carpatides de la Serbie orientale (couches de Vrbovac). *Bullétin du Muséum d'Histoire Naturelle. Serie A*, 25, 35-39,(Beograd), *Reprinted in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 470-473 .

Milovanović, B. & Grubić, A., 1972. Upper Cretaceous of eastern Serbia. *Bullétin du Muséum d'Histoire Naturelle. Serie A*, 27, 115-127, (Beograd).

Milovanović, B. & Sladić, M., 1957. Les nouvelles espèces du genre Pseudopolyconites Mil.. *Bullétin du Service Géologique et Géophysique de la R.P. de Serbie*, 13, 193-240, 6pl. (Beograd) *Reprinted in special volume edited by M. Sladic-Trifunovic and A. Grubic prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 431-451 .

Milovanović, B. (Translated by A. Grubić), 1984. Two rudist genera from the Dinarides. *Institut de recherches geologiques et geophysiques, Vjesnik, Série A*, 42, 97-110, 4 pl. excl. (In Serbo-Croat with English summary).

Milovanović, B., Sladić, M. & Grubić, 1972. Proprietés taxonomiques et morphologiques de quelques espèces du genre rudistique Pironaea. *Annales Géologiques de la Péninsule Balkanique*, 37 (1), *French résumé published in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* p. 476-487 .

Negra, M. & Philip, J., 1987. Stratigraphie et paléontologie des formations à rudistes et grands forminifères du Campanien supérieur du Jebel Kebar (Tunisie Centrale). *Géologie Méditerranéenne*, 12-13 (1987) (1/2), 49-57.

Neumann, M & Robaszynski, F., 1985. Tentative de comparaison entre la limite supérieure du Campanien stratotypique et la limite inférieure du Maastrichtien stratotypique. *Géologie Méditerranéenne*, 10 (1983) (3-4), 73-79.

Obradovich, J.D., 1988. A different perspective on glauconite as a chronometer for geologic time scale studies. *Paleoceanography*, 3 (6), 757-770.

Özer, S., 1988. Distributions stratigraphiques et géographiques des rudistes du Crétacé Supérieur en Turquie. Abstract in: *M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988*, p. 16.

Palmer, M.R. & Elderfield, H., 1985. Sr isotope composition of sea water over the past 75 Myr. *Nature*, 314, 526-528.

Pamouktchiev, A, 1962. Faune rudiste du Crétacé Supérieur en Bulgarie. I. Sur certains Hippurites de l'arrondissement de Breznik, Bulgarie de l'ouest.. *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 2, Géologie*, 56, 99-114, 6 pl. excl. (In Bulgarian with French summary).

Pamouktchiev, A, 1964. Faune rudiste du Maëstrichtien de l'arrondissement de Breznik, (II). *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 58, 25-46, 7 pl. excl. (In Bulgarian with French summary).

Pamouktchiev, A, 1965. *Pironaea polystyla garlensis* subsp. nov. du Maëstrichtien de la région de Breznik. *Review of the Bulgarian Geological Society*, 26 (2), 206-208. (In Bulgarian with French summary).

Pamouktchiev, A., 1966. Répresentants Maestrichtiens du genre *Biradiolites* Orbigny de la région de Breznik (Bulgarie de l'ouest). *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 60, 31-74, 3 pl., 1 encl. excl. (In Bulgarian with French summary).

Pamouktchiev, A., 1967. Sur le niveau stratigraphique des répresentants du genre *Batolites* Montfort. *Association Géologique Carpatho-Balkanique. Viii-ème congrés.*

Belgrade. Septembre 1967. Rapports. Paleontologie, 529-532, Radisa Timotic, Beograd.

Pamouktchiev, A., 1969. Répresentants Maëstrichtiens du genre *Lapeirousia* , Bulgarie de l'ouest. *Bulgarian Academy of Sciences, Bulletin of the Geological Institute - Series Palaeontology*, 18, 71-82, 4 pl. excl. (In Bulgarian with French summary).

Pamouktchiev, A, 1970. Sur la présence de Maestrichtien près de Kainachbeckens (Autriche). *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 62, 47-52. (In Bulgarian with French summary).

Pamouktchiev, A., 1974. Sur quelques espèces de la famille Caprinidae du Balkan central et du Srednogorié occidental. *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 66, 15-23, 4 pl. excl. (In Bulgarian with French summary).

Pamouktchiev, A., 1975a. Origine et phylogénie du genre *Pironaea* (Hippuritidae, Maestrichtien) de l'Europe de Sud-Est et d'Asie Mineure. *Geologica Balcanica*, 5 (2), 81-92.

Pamouktchiev, A., 1975b. Espèces nouvelles d'Hippurites en Bulgarie. *Palaeontology, Stratigraphy and Lithology*, 1, 37-45, 2 pl., (Sofia).

Pamouktchiev, A., 1975c. Espèces nouvelles de *Pironaea* (Hippuritidae). *Palaeontology, Stratigraphy and Lithology*, 3, 19-26, 5 pl., (Sofia).

Pamouktchiev, A.M., 1976. *Hippurites tzankovi* sp. nov. du Maestrichtien de la région de Breznik (Bulgarie de l'ouest). *Review of the Bulgarian Geological Society*, 37 (2), 221-223.

Pamouktchiev, A., 1977. Successions d'Hippurites en Bulgarie. *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 69, 233-240. (In Bulgarian with French summary).

Pamouktchiev, A., 1978. Ontogenese de representants de la famille d'Hippuritidae (Bivalvia). *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 70, 125-133. (In Bulgarian with French summary).

Pamouktchiev, A.M., 1979a. Faune de Rudistes du Maestrichtien en Bulgarie (de l'Arrondissement de Breznik) III.. *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 73, 213-246, 9 pl. excl.(In Bulgarian with French summary).

Pamouktchiev, A., 1979b. Origine d'*Hippuritella heritschi* (Hippuritidae, Rudistae). *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 71, 401-404. (In Bulgarian with French summary).

Pamouktchiev, A., 1979c. Lignees de *Vaccinites sulcatus* (Hippuritidae, Rudistae). *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 71, 405-411. (In Bulgarian with French summary).

Pamouktchiev, A., 1982. Revisions de quelques Hippurites (Rudistae) du Maestrichtien. *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 76, 97-103, 3 pl. (In Bulgarian with French summary).

Pamouktchiev, A.M., 1983. *Dessia* N. Gen. (Bivalvia Hippuritoida) - un nouveau genre du Maestrichtien superieur en Bulgarie.*Comptes rendus de l'Academie bulgare des Sciences*, 36 (7), 931-932.

Parona, C.F., 1908. Notizie sulla fauna a rudiste della pietra di Subiaco nella valle dell'Aniene. *Bolletino della società geologica Italiana*, 27 fasc. 3, 299-310, 1 encl. excl.

Pascual, O., Pons, J.M. & Vicens, E., 1987. Rudist horizons in the Montsec (South Central Pyrenees). *Kreide Kongres, Tübingen*, 1987.

Patrulius, D., 1974. Duranddelgaia et Miseia, deux nouveaux genres de rudistes du Sénonien de Padurea craiului (Monts Apuseni). *Dari de seama ale sedintelor*, 60 (1972-73), 169-180, 5pl., 1 fig. excl. (In Romainian with French summary).

Pavlovec, R., 1979. Geotectonical units of Yugoslavia. In: *Proceedings of the 16th European Micropaleontological Colloquium*, 5-10, 1 fig. incl., Ljubljana.

Peake, N.B. & Hancock, J.M., 1978. The Upper Cretaceous of Norfolk. In: *Larwood, G.P. & Funnell, B.M. (eds.) The geology of Norfolk.* 293-240.

Pejović, D., 1967. *Sabinia rtanjica* n. sp. from the Maestrichtian of eastern Serbia. *Institut de Recherches Geologiques et Geophysiques, Vjesnik, Série A*, 24-25, 331-336.

Pejović, D., 1969. Some rudists from Montenegro. *Bulletin of the Institute for Geological and Geophysical Research (Geology). Series A*, 26, 217-236.

Pejović, D., 1970. Two new species of rudists from the Maastricht sediments of the Island of Brač. *Bulletin Scientifique Yugoslavie, Section A*, 15 (7-8), 244-245 (Beograd).

Pejović, D., 1979. Bournonia hvarensis and Distefanella radiocicae new Senonian radiolitids from Hvar Island. *Bullétin de l'Académie Serbe des Sciences Mathématiques et Naturelles. B. Sciences Naturelles*, 19, 123-126, 2 figs. incl., 3 pl. excl. (Beograd).

Pejović, D. & Radoičić, R., 1987. Contribution to the study of Upper Cretaceous stratigraphy of Brac. *Geologija Razprave in Poročila*, 28/29, 121-150.

Pejovic, D. & Sladic-Trifunovic, M., 1977. First occurence of Pseudopolyconites in older Senonian sediments. *Annales Géologiques de la Péninsule Balkanique*, 41, 175-180, 7 pl.excl.

Peza, L.H., 1988. The Senonian with rudists in S-E Albania. Abstract in: *M. Sladić-Trifunović (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988*, p. 19.

Philip, J., 1972. Paléoécologie des formations à rudistes du Crétacé Supérieur - l'exemple du sud-est de la France. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 12, 205-222.

Philip, J., 1982. Paléobiogéographie des Rudistes et géodynamique des marges mésogéennes au Crétacé supérieur. *Bullétin de la Société géologique de France*, 24 (5-6), 995-1006.

Philip, J., 1985a. Le Campanien et le Maastrichtien à rudistes et grands foraminifères de Quatretonda (Province de Valence, Espagne): une clef pour la biozonation et les corrélations stratigraphiques dans le domaine mésogéen. *Géologie Méditerranéenne*, 10 (1983) (3-4), 87-98.

Philip, J., 1985b. Sur les relations des marges téthysiennes au Campanien et au Maastrichtien déduites de la distribution des Rudistes. *Bullétin de la Société géologique de France*, 5 (8), 723.

Philip, J., 1986. Étude paléontologique du genre *Sabinia* (rudiste à canaux) des récifs du Campanien de Tunisie. *Geobios*, 19 (2), 247-251, 1 pl. excl.

Philip, J. & Allemann, J., 1982. Comparaison entre les plates-formes du Crétacé Supérieur de Provence et de Sardaigne. *Cretaceous Research*, 3, 35-45.

Philip, J. & Bilotte, M., 1985. Les rudistes du Sénonien de la France. Précisions

stratigraphiques sur le Dordonien. *Géologie Méditerranéenne*, 10 (1985) (3-4), 183-192.

Philip, J. & Platel, J.-P., 1987. Sur la présence du genre *Torreites* (Rudist de la Province Caraïbe) dans le Campanien du Dhofar (Sud de l'Oman): conséquences sur l'évolution paléobiogéographique du Pacifique et de l'Océan Indien au Crétacé. *Comptes rendues de Académie de Science. Paris (Série II)*, 304 (12), 679-684.

Pirini Radrizzani, C., Tunis, G. & Venturini, S., 1986. Biostratigrafia e paleogeografia dell'area sud-occidentale dell'anticlinale M.Mia-M.Matajur (Prealpi Giulie). *Rivista Italiana Paleontologia e Straigrafia.*, 92 (3), 327-382.

Platel, J.-P., 1977. Le Campanien stratotypique dans le synclinal de Saintes (Charentes): lithostratigraphie, géomorphologie et biozonation. *Bullétin du bureau de recherches géologiques et miniéres. Paris*, Section 1 (no. 4), 261-276.

Pleničar, M, 1973. Radiolites from the Cretaceous beds of Slovenia, Part I. *Geologija-Razprave in Poročila*, 16, 187-226, 15 pl. incl., Ljubljana. (In Serbo-Croat with English summary).

Pleničar, M, 1974. Radiolites from the Cretaceous beds of Slovenia, Part II. *Geologija-Razprave in Poročila*, 17, 131-179, Ljubljana. (In Serbo-Croat with English summary).

Pleničar, M, 1975. Hippuritidae of Nanos and the Trieste-Komen Plain. *Academia Scientiarum et Artium Slovenica, Classis IV: Historia Naturalis. Dissertationes*, 18 (4), 1-35, 23 pl. excl. (In Serbo-Croat with English summary).

Pleničar, M, 1977. Rudists from the Cretaceous beds of Slovenia. *Geologija-Razprave in Poročila*, 20, 5-31, 2 figs., 8 pl. incl., Ljubljana. (In Serbo-Croat with English summary).

Pleničar, M, 1979. Cretaceous beds in Slovenia. In: *Proceedings of the 16th European Micropaleontological Colloquium*, 37-47. Ljubljana.

Pleničar, M, 1983. The living environment of the Cretaceous fauna in the Northwestern Dinarides. *Bollettino della Società Paleontologica Italiana*, 22 (1-2), 49-51.

Pleničar, M, 1985. Senonian rudistid biostromes north of Kocevje (Slovenia, NW Yugoslavia). *Razprave IV Razreda Sazu*, 26, 247-258, 2 pl. excl.

Pleničar, M & Pavlovec, R., 1981. New views of the development of Maastrichtian in Slovenia. *Mining and Metallurgy Quarterly*, 28 (4), 383-386,, (In Serbo-Croat with English summary).

Pleničar, M & Šribar, L., 1983. Cretaceous beds between Kočevje and Krka. *Geološki vjesnik*, 4, 47-79, 6 figs. incl. 7 pl. excl., Ljubljana(In Serbo-Croat with English summary).

Polšak, A., 1965. Joufia reticulata Boehm dans le Maestrichtien de Bešpelj au nord de Jajce (Bosnie). *Geološki vjesnik*, 18 (1964) (2), 337-340,, Zagreb.

Polšak, A., 1967. *Milovanovicia* , un nouveau genre de Rudistes de la famille des Radiolitidés. *Bullétin de la Société géologique de France*, 9 (7), 758-761.

Polšak, A., 1979. Cretaceous biolithic complexes of the Pannonian Basin and adjacent areas - their importance from the palaeogeographical, palaeotectonical and oil-geological standpoint. *Zbornik radova, Ananstveni Savjet za naftu JAZU Zagreb*,

Polšak, A. & Mamužić, P., 1969. Les nouveaux gisements de rudistes dans le Crétacé Supérieur des Dinarides Externes. *Geološki Vjesnik*, 22, 229-245, 1 encl. excl., Zagreb(In Serbo-Croat with English summary).

Pons, J.-M. & Vicens, E., 1988. Campanian and Maastrichtian rudists from southern

Valencia Province, South East Spain. Abstract in: M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988, , 24.

Popp, B.N., Podosek, F.A., Brannon, J.C., Anderson, T.F. & Pier, J., 1986. 87Sr/86Sr ratios in Permo-Carboniferous sea water from the analyses of well-preserved brachiopod shells. *Geochimica et Cosmochimica Acta*, 50, 1321-1328.

Radoičič, R., 1982. Carbonate platforms of the Dinarides: the example of Montenegro-West Serbia sector. *Bullétin de l'Académie des Sciences Mathématiques et Naturelles. B. Sciences Naturelles*, 80 (22), 35-46, 5 figs.

Richter, F.M. & DePaolo, D.J., 1987. Numerical models for diagenesis and the Neogene Sr isotopic evolution of seawater from DSDP site 590B. *Earth and Planetary Science Letters*, 83, 27-38.

Richter, F.M. & DePaolo, D.J., 1988. Diagenesis and Sr isotopic evolution of seawater using data from DSDP 590B: and 575. *Earth and Planetary Science Letters*, 90, 382-394.

Rundberg, Y. & Smalley, P.C., 1989. High-resolution dating of Cenozoic sediments from northern North Sea using 87Sr/86Sr stratigraphy. *The American Association of Petroleum Geologists Bulletin*, 73(3), .

Saint-Marc, P., 1963. Étude géologique de la région de Barcis (Alpes méridionales, province d'Udine, Italie). *Bullétin de la Société géologique de France*, 5 (7), 803-808.

Sánchez, V.M.,, 1981. *Hippuritidae y Radiolitidae (Bivalvia). Catalogo de especies, Universidad Autonoma de Barcelona, Publicaciones de Geologia*, No. 15.

Schulz, M.-G. & Schmid, F., 1983. Das Ober-Maastricht von Hemmoor (N-Deutschland): Faunenzonen-Gliederung und Korrelation mit dem Ober-Maastricht von Dänemark und Limburg. *Newsletter in Stratigraphy*, 13 (1), 21-39.

Signal, 1977. Essai de zonation du Crétacé méditerranéen à l'aide des foraminifères planctoniques. *Géologie Méditerranéenne*, 4 (2), 99-108.

Sirna, G., 1983. *Apricardia pachiniana* , a new species from the Maastrichtian near Pachino (Southeastern Sicily). *Bollettino della Società Paleontologica Italiana*, 22 (3), 301-303. (The Earth Sciences Society of the Libyan Arab Republic).

Skelton, P.W., 1978. The evolution of functional design in rudists (Hippuritacea) and its taxonomic implications. *Philosophical transactions of the Royal Society of London. Series B.*, 284, 305-318.

Skelton, P.W., 1985. Preadaptation and evolutionary innovation in rudist bivalves. *Special Papers in Palaeontology*, 33, 159-173.

Skelton, P.W. & Gili, E., in press. Palaeoecological classification of rudist morphotypes. In: *M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988.*

Skelton, P.W. & Wright, V.P., 1987. A Caribbean rudist bivalve in Oman: island hopping across the Pacific in the late Cretaceous. *Palaeontology*, 30, 505-529.

Skelton, P.W., Nolan, S.C. & Scott, R.W., 1990. The Maastrichtian transgression onto the northwestern flank of the Proto-Oman Mountains: sequences of rudist-bearing beach to open shelf facies. In: *A.H.F. Robertson, M.P. Searle & A.C. Ries (eds.), The geology and tectonics of the Oman region.Geological Society Special Publication*, 49, 521-547.

Sladić-Trifunović, M., 1970. *Hippurites heritschi* and the Maastrichtian rudist horizons in the Senonian sediments at St. Bartholomä (Kainachbecken, Austria). *Annales Géologiques de la Péninsule Balkanique*, , 421-425, 7 pl. excl. (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1967a. Sur les Pironea de l'île de Brač. *University of Beograd. Transactions of the Mining and Geological fakulties*, 9-10, 283-291. (In Serbo-Croat with French summary).

Sladić-Trifunović, M., 1967b. Über die Bedeutung der neuen Exemplare der Pironaeenfauna von Dragačevo (Westserbien) in Bezug auf die Unterart *Pironaea polystyla slavonica* (Hilber) Kühn. *Annales Géologiques de la Péninsule Balkanique*, 33, 243-270, 24 figs. incl., 4 pl. excl. (In Serbo-Croat with German summary).

Sladić-Trifunović, M., 1967c. *Hippurites braciensis* n. sp. und die biostratigraphische Bedeutung einiger senonischer Hippuriten. *Annales Géologiques de la Péninsule Balkanique*, 33, 141-155, 13 figs. incl., 4 pl. excl. (In Serbo-Croat with German summary).

Sladić-Trifunović, M., 1972. Senonian limestones with orbitoides and rudists from Kozluk (northeastern Bosnia). *Annales Géologiques de la Péninsule Balkanique*, 37, 111-150, 15 figs. incl., 13 pl. excl. (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1977. Hippurites from the Maestrichtian sediments of eastern Serbia. *Annales Géologiques de la Péninsule Balkanique*, 17, 257-268, 4 figs. incl., 5 pl. excl. (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1979. Pironaea branislavi, a new pironaean species from the Maestrichtian sediments of the Vrbovac reef, loc. Bačevica, eastern Serbia. *Annales Géologiques de la Péninsule Balkanique*, 42, 401-412, 3 fig. incl., 5 pl. excl.(In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1980. Maastrichtian rudists from orbitoid limestones of Pokonji Dol on the Island of Hvar. *Annales Géologiques de la Péninsule Balkanique*, 43-44, 293-301, 6 pl. excl. (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1981a. *Branislavia* , A new rudist genus from Maastrichtian of Bačevica in East Serbia. *Annales Géologiques de la Péninsule Balkanique*, 45, 207-216, 7 pl. excl. (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1981b. Discovery of Colveraias in the Maastrichtian of Yugoslavia (Islands of Brač and Hvar). *Annales Géologiques de la Péninsule Balkanique*, 45, 221-227, 7 pl. excl. (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1983. Paleontological characteristics and biostratigraphic significance of Pseudopolyconites. . *Annales Géologiques de la Péninsule Balkanique*, 47, 212-309, 28 fig. incl., 48 pl. excl. *Translated into French in special volume edited by M. Sladic-Trifunovic and A. Grubic prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.* (In Serbo-Croat with English summary).

Sladić-Trifunović, M., 1987. Pironaea-Pseudopolyconites Senonian of the Apulian plate: palaeobiogeographic correlations and biostratigraphy. *Memorie della Società geologica Italiana*, 40, 149-162.

Sladić-Trifunović, M., 1988. Different facial types of Senonian sediments *with rudists in Yugoslavia, from three particular palaeogeographical areas in the Tethys. In: M. Sladić-Trifunović, (ed.), Guide book for the First International Conference on rudists, held in Belgrade, 1988*, 17-20.

Sladić-Trifunović, M. & Campobasso, V., 1980. Pseudopolyconites and Colveraias from Maastrichtian of Poggiardo (Lecce, Puglia), Italy. *Annales Géologiques de la Péninsule Balkanique*, 43-44, 273-286, 7 pl. excl.

Sladić-Trifunović, M. & Pejović, D., 1977. A new radiolitid genus from the Senonian sediments of Fundinia (Montenegro) and Povlja (Brač island). *Annales Géologiques de la Péninsule Balkanique*, 41, 221-233. (In Serbo-Croat with English summary).

Sohl, N.F. & Kollmann, H.A., 1985. *Cretaceous Actaeonellid gastropods from the western hemisphere. Geological survey professional paper 1304*, 104pp, 23 pl. excl. U.S. Govt. printing office, Washington.

Souquet, P., Peybernes, B., Bilotte, M., Deobras, E.J., Rey, J. & Canerot, J., 1977. Nouvelle esquise structurale des Pyrénées. *Ann. Cent. Rég. Doc. Ped. Toulouse, Guide des ressources pédagogiques pour l'académie de Toulouse, 3ème livret, Géologie*, , 127-143, 8pl., 1 map. Toulouse.

Surlyk, F., 1970. Die Stratigraphie des Maastricht von Dänemark un Norddeutschland aufgrund von Brachiopoden. *Newsletter in Stratigraphy*, 1, 5-16.

Surlyk, F., 1984. The Maastrichtian Stage in NW Europe, and its brachiopod zonation. *Bulletin of the geological Society of Denmark*, 33, 217-223.

Swinburne, N.H.M. & Noacco, A,. The platform carbonates of M. Jouf, Maniago, and the Upper Cretaceous stratigraphy of the Italian Carnian Prealps. *Journal of the Geological Society of London* (submitted).

Toucas, A., 1903. Études sur la classification et l'évolution des Hippurites. *Mémoire de la Société géologique de France*, 30, 128pp, 8 pl., 3 tables excl. Reprinted Swets & Zeitlinger, 1966, Amsterdam.

Toucas, A., 1907-1909. Études sur la classification et l'évolution des Radiolitidés. *Mémoire de la Société géologique de France*, 36, 132pp, 17 pl., 4 tab. excl. Reprinted Swets & Zeitlinger, 1966, Amsterdam.

Tzankov, V., 1965. *Mitrocaprina bulgarica* n. sp. du Maestrichtien de la Bulgarie du S.W.. *Annulaire de l'Université de Sofia, Faculté de Biologie, Géologie et Géographie, Livre 1, Géologie*, 58 (63-64), 13-19.

Van Gorsel, J.T., 1978. Late Cretaceous orbitoidal foraminifera. In: R.H. Hedley & C.G. Adams (eds.), *Foraminifera* , 3, 1-20. Academic Press, London.

Van Hinte, E.-J., 1976. A Cretaceous time scale. *American Association of Petroleum Geologists Bulletin*, 60 (4), 498-516.

Veizer, J., 1983a. Chemical diagenesis of carbonates: theory and application of trace element techinque. In: *Stable isotopes in sedimentary geology (eds. Arthur, M.A. et al.), S.E.P.M., short course 10*, chapter 3, 1-100, .

Veizer, J., 1983b. Trace elements and isotopes in sedimentary carbonates. In: *Carbonates: mineralogy and chemistry (ed. Reeder. R.J.), Vol, 11, Min. Soc. America, Reviews in Mineralogy*, Chapter 8, 265-300, .

Vogel, K., 1970. Die Radioliten-Gattung *Osculigera* Kühn (höhere Oberkreide) und die Funktion kennzeichnender morphologischer Eigenschaften der Rudisten. *Paläontologische Zeitschrift*, 44 (1/2), 63-81.

Yanin, B.T., 1988. The fauna of Jurassic and Cretaceous rudists of the USSR. Abstract in: *M. Sladic-Trifunovic (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, by Serbian Geological Society, October, 1988*, p. 32.

87/86Sr from data in Koeprick et al. 1985

			Age det on basis of Harland et al. 1982		SeaW	0.70907	+/-4 (1sigma)			SeaW	
			P/M = 65Ma, M/C=73.5Ma		E&A	0.70797				E&A	
DSDP samples			C/S=		NBS-987	0.71014				NBS-987	
Sample no.	Core, section, interval	Foram zone	Nannofossil zone	stage	age (Ma.)	87/86 Sr	Sr (ppm)	insol. residue (Wt. %)	lithology	age (Ma.)	norm via sea as .709158
Leg 17, site 167, Magellan Rise, Central Pacific Basin											
4375	38, c.c.	P3	CP3?	Thanetian	59.3	0.70793	1285	6.5	cherty limestone	59	0.708018
4376	39,1,109-110	P2	CP2?	Danian	61.6	0.70778	1258	1.2	limestone	62	0.707848
4377	40,c.c.,	P1	CP1	Danian	64.0	0.70781	1012	4.7	cherty limestone	64	0.707898
4378	42,4,119-120	Globotruncana mayaroensis	Lithraphradites quadratus	U. Maas.	68.8	0.70770	802	1.9	nannofossil chalky limestone	69	0.707788
4379	45,6,98-99	Globotruncana gansseri	Tetralithus trifidus	L. Maas.	71.1	0.70770	1151	5.5	nannofossil chalk	71	0.707788
4380	48,c.c.,	Globotruncana stuarti	Tetralithus trifidus	L. Maas.	73.0	0.70765	1102	3.3	nannofossil chalk	73	0.707738
4381	50,1,99-100	Globotruncana ciacrata	Bronsonica parca	U. Camp.	74.3	0.70769	1197	2.6	nannofossil chalk	74	0.707778
4382	55,2,99-100	Globotruncana stuartiformis	Eiffellithus eximius	L. Camp.	80.3	0.70755	784	3.1	nannofossil chalk	80	0.707638
Leg 22, Site 216, Crest, Ninetyeast, Indian Ocean										61	0.707868
4579	23,1,100-101	P3/2	CP1b?	Thanetian	60.6	0.70778	641	0.6	foram-nanno chalk	65	0.707818
4580	24,3,75-76	Globortalia mayroensis		U. Maas.	65.1	0.70773	763	1.1	foram chalk	66	0.708078
Non-DSDP samples										70	0.707698
	Formation								lithology	71	0.707718
Location : Denmark, Stevns Klint, just below K/T boundary										84	0.707538
	Bryozoan Lst.			U. Maas.	65.9	0.70799	615	0.8	lime mudstone	84	0.707488
Location : Iran										84	0.707538
3270	Eman Hassan			L. Maas.	70.3	0.70761	737	6.7	mollusk echinoderm lime pkst.	85	0.707528
3271	Eman Hassan			L. Maas.	70.7	0.70763	1072	2.6	echinoderm lime pkst.	85	0.707488
3357	Ilam			U. Sant.	83.8	0.70745	1268	4.5	foram lime pkst.	86	0.707518
3349	Ilam			U. Sant.	84.2	0.70740	1278	4	foram lime wkst.	86	0.707558
3355	Ilam			U. Sant.	84.4	0.70745	1485	3.4	foram lime wkst/pkst.	86	0.707458
3351	Ilam			L. Sant.	84.5	0.70744	1262	8.7	foram lime wkst.	87	0.707508
3347	Ilam			L. Sant.	85.3	0.70740	1238	2.8	foram lime pkst.	87	0.707478
3352	Ilam			L. Sant.	85.6	0.70743	1211	9.2	foram lime wkst.	88	0.707468
3356	Ilam			L. Sant.	86.2	0.70747	1381	2.1	foram lime pkst.	67	0.708008
3278	Ilam			L. Sant.	86.4	0.70737	1049	3.3	foram peloid lime pkst.	67	0.707938
3354	Ilam			L. Sant.	86.5	0.70742	1133	2.3	foram lime pkst.	67	0.707948
3348	Ilam			L. Sant.	87.1	0.70739	1148	2.9	foram lime wkst.	68	0.707948
3350	Ilam			L. Sant.	87.5	0.70738	836	1.7	foram peloid lime pkst.	67	0.707888
The Netherlands, South Limburg/Maastricht area, St. Pietersburg										73	0.707638
2792	Maastricht			U. Maas.	66.8	0.70792	811	0.4	echinoderm mollusk lime grnst	65	0.707898
2793	Maastricht			U. Maas.	66.9	0.70785	647	0.5	echinoderm mollusk lime grnst	68	0.707778
2794	Maastricht			U. Maas.	67.3	0.70786	588	1.9	foram mollusk lime grnst.	70	0.707828
2795	Gulpen			U. Maas.	68.0	0.70786	641	0.6	foram mollusk lime pkst.	81	0.707578
2796	Maastricht			U. Maas.	67.1	0.70780	716	8.6	mollusk lime pkst.	81	0.707508
Alaska, USA										66	0.707848
3095	Kaguyak			U. Camp.	73.0	0.70755	630	0.7	*Pachydiscus ootacodensis*	*68.2*	*0.707948*
N. Carolina, USA										77	0.707608
4307-3	Pedee			U. Maas.	65.2	0.70781	920	0	fossiliferous sst.	85	0.707618
4307-2	Pedee			U. Maas.	67.7	0.70769	903	0	fossiliferous sst.	85	0.707468
4307-1	Pedee			U. Maas.	70.3	0.70774	952	0	fossiliferous sst.	86	0.707328
3695	Black Creek			L. Camp.	80.6	0.70749	577	0.7	mixed mollusk frags.	86	0.707458
3696	Black Creek			L. Camp.	80.9	0.70742	1001	0.6	mixed mollusk frags.	86	0.707438
Tennessee, USA										87	0.707438
3659	Prairie Bluff			U. Maas.	65.7	0.70776	813	0	*Exogyra costata*	*87.1*	*0.707378*
Texas, USA											
4220	Kemp Clay			U. Maas.	68.2	0.70786	1836	5.9	mixed foraminifera		
3611	Taylor			L. Camp.	77.4	0.70752	780	0.1	mixed mollusc fragments		
3303	Taylor-Austin contact			M. Sant.	85.3	0.70753	1000	3	mixed sharks teeth		
3304	Taylor-Austin contact			M. Sant.	85.3	0.70738	1094	9.5	calcium phosphate nodules		
2014	Austin			L. Sant.	85.7	0.70724	1382	2	mollusk lime wkst.-mdst.		
1528	Austin			L. Sant.	85.9	0.70737	1181	8.4	lime wkst.-mdst.		
4160	Austin			L. Sant.	86.3	0.70735	952	9.6	mixed mollusk frags.		
2128	Austin			L. Sant.	86.5	0.70735	877	7.2	foram lime pkst.-wkst.		
4161	Austin			L. Sant.	87.1	0.70729	796	9.1	mixed mollusk frags.		

87/86Sr data from Hess et al. 1986

Core section interval	Age in Ma	Ratio	+ / -	
P/M=66.5Ma	Berggren	.709198	20	SeaW
M/C=74.5Ma	1985	.708000		E&A
C/S=?		.710220		NBS-987
				Recalc acc
Leg 32, site 305, Shatsky Rise, North Pacific				NBS-987=0.7
	60	.707727	34	0.707737
	61	.707794	18	0.707804
14-5-25-27	61.9	.707824	20	0.707834
15-3-10-12	63	.707764	18	0.707774
16-5-21-23	66.3	.707877	24	0.707887
17-5-10-12	67	.707782	20	0.707792
17-6-29-31	67.1	.707788	32	0.707798
18-3-70-72	69	.707756	16	0.707766
18-6-28-30	69.9	.707774	18	0.707784
19-6-28-30	71.1	.707760	22	0.707770
20-5-28-30	72.1	.707759	24	0.707769
21-6-28-30	73.2	.707653	34	0.707663
23-6-28-30	75.1	.707679	34	0.707689
24-5-28-30	75.9	.707705	14	0.707715
25-6-28-30	77	.707567	20	0.707577
27-2-25-27	78.3	.707531	24	0.707541
28-2-36-38	79.2	.707597	16	0.707607
31-CC	84	.707487	18	0.707497
32-CC	85.3	.707489	18	0.707499
39-CC	96.8	.707438	30	0.707448
43-3-25-27	100.9	.707375	18	0.707385
				0.707969
Leg 86, site 577, Shatsky Rise, N. Pacific				0.707880
12-1-39-41	64	.707873	32	0.707883
12-2-29-31	64.5	.707817	18	0.707827
12-3-29-31	65	.707854	20	0.707864
12-4-49-51	65.5	.707877	20	0.707887
12-5-19-21	66	.707959	28	0.707978
13-3-99-101	67	.707870	16	0.707869
Leg 39, site 356, Sao Paolo Plateau, South Atlantic				
29-3-5-7	66.2	.707968	24	
29-4-96-98	66.5	.707859	22	

Boreal samples (first set) for Sr analysis

No.	No.	No.	Locality description	Biostrat. zone
Belemnites from various localities, assigned to belemnite zones				
Bo	1	1		Sant. unidiv.
Bo	1	2		Sant. unidiv.
Bo	2	1	Ignaberga New Quarry, South Sweden	Gonioteuthis quadrata scaniensis
Bo	2	2	Ignaberga New Quarry, South Sweden	Gonioteuthis quadrata scaniensis
Bo	2	3	Ignaberga New Quarry, South Sweden	Gonioteuthis quadrata scaniensis
Bo	3	B1	Balsrik Quarry, S. Sweden, 6km NNE of Kristiansand, Greensand	Base of Belemnitella mucronata zone
Bo	3	B2	Balsrik Quarry, S. Sweden, 6km NNE of Kristiansand, Greensand	Base of Belemnitella mucronata zone
Bo	3	B3	Balsrik Quarry, S. Sweden, 6km NNE of Kristiansand, Greensand	Base of Belemnitella mucronata zone
Bo	4	1	Weybourne gamma	Top part of Belemnitella mucronata zone
Bo	4	2	Weybourne gamma	Top part of Belemnitella mucronata zone
Bo	4	3	Weybourne gamma	Top part of Belemnitella mucronata zone
Bo	5	1	Weybourne below z	Lowest part of zone of Belemnitella minor
Bo	5	2	Weybourne below z	Lowest part of zone of Belemnitella minor
Bo	5	3	Weybourne below z	Lowest part of zone of Belemnitella minor
Bo	6	1	Weybourne around u	Lowest part of zone of Belemnitella minor
Bo	6	2	Weybourne around u	Lowest part of zone of Belemnitella minor
Bo	6	3	Weybourne around u	Lowest part of zone of Belemnitella minor
Bo	7	1	East of Ordon Gill, Beeston Chalk (ie. approx. middle of the Beeston Chalk)	Prob. top of zone of Belemnitella minor
Bo	7	2	East of Ordon Gill, Beeston Chalk (ie. approx. middle of the Beeston Chalk)	Prob. top of zone of Belemnitella minor
Bo	7	3	East of Ordon Gill, Beeston Chalk (ie. approx. middle of the Beeston Chalk)	Prob. top of zone of Belemnitella minor
Bo	8	1	Shore below Cromer lighthouse erratic, more westerly of flint spreads	Somewhere above middle of zone of Belemnitella langei
Bo	8	2	Shore below Cromer lighthouse erratic, more westerly of flint spreads	Somewhere above middle of zone of Belemnitella langei
Bo	8	3	Shore below Cromer lighthouse erratic, more westerly of flint spreads	Somewhere above middle of zone of Belemnitella langei
Bo	9	1	Pyramida flint spread at Overstrand = Echinocorys pyramida bed	Prob. top of zone of Belemnitella langei
Bo	9	2	Pyramida flint spread at Overstrand = Echinocorys pyramida bed	Prob. top of zone of Belemnitella langei
Bo	9	3	Pyramida flint spread at Overstrand = Echinocorys pyramida bed	Prob. top of zone of Belemnitella langei
Bo	10	1	Sidestrand, Norfolk, between P & Q	Prob. zone of Belemnitella obtusa
Bo	10	2	Sidestrand, Norfolk, between P & Q	Prob. zone of Belemnitella obtusa
Bo	10	3	Sidestrand, Norfolk, between P & Q	Prob. zone of Belemnitella obtusa
Bo	11	1	Trimmingham, top of sponge beds or just above	Zone of Belemnitella sumensis
Bo	11	2	Trimmingham, top of sponge beds or just above	Zone of Belemnitella sumensis
Bo	11	3	Trimmingham, top of sponge beds or just above	Zone of Belemnitella sumensis
Bo	12	1	"Dania"pit at Hadsund nr Mariager, Jutland, Denmark	Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	12	3	"Dania"pit at Hadsund nr Mariager, Jutland, Denmark	Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	12	4	"Dania"pit at Hadsund nr Mariager, Jutland, Denmark	Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	12	5	"Dania"pit at Hadsund nr Mariager, Jutland, Denmark	Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	13	Mi1	Holtug Quarry, Denmark	Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	13	Mi2	Holtug Quarry, Denmark	Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	14	Ec1		Belemnella casimirovensis and stevensis/chitoniformis zones
Bo	14	Mi1		Belemnella casimirovensis and stevensis/chitoniformis zones

Boreal samples (first set) for Sr analysis

No.	No.	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ /	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ /	87/87 Sr	+ / -	87/87 Sr	+ /
		11.5.89.		20.5.89.		27.5.89.		5.6.89.				22.10.89.		29.10.89.		5.11.89.		4.2.90.		10.2.90.	
		'396		'402		'406		'413				'506		'512		'516		'581		'587	
		0.710192	10	0.710216	11	0.710250	10	0.710210	10	0.710241	10	.710242*	11	0.710250	10	0.710186	10	0.710208	11	0.710163	10
		0.710234	11	0.710252	10	0.710200	11			0.710229	10			0.710211	8	0.710240	10	0.710188	11	0.710181	10
1	1																	0.707438			
1	2																			0.707455	10
2	1											0.707503	10								
2	2													0.707494	12						
2	3															0.707516	11				
3	B1	0.707507	11																		
3	B2	0.707538	11																		
3	B3	0.707538	10																		
4	1	0.707568	10																		
4	2	0.707566	10																		
4	3	0.707551	11																		
5	1	0.707573	10																		
5	2	0.707572	10																		
5	3	0.707576	10																		
6	1	0.707568	10																		
6	2	0.707567	10																		
6	3			0.707565	11																
7	1			0.707663	8					0.707660	10										
7	2			0.707617	9					0.707663	14										
7	3			0.707647	10					0.707676	10										
8	1			0.707694	10																
8	2			0.707710	10																
8	3			0.707703	11																
9	1			0.707623	11																
9	2			0.707633	11																
9	3			0.707657	10																
10	1			0.707751	10			x													
10	2					0.707708	11	0.707760	10												
10	3					0.707728	12	0.707755*	28												
11	1					0.707699	10	0.707729	10												
11	2					0.707736	12	0.707800	12												
11	3					0.707780	12	0.707752	11												
12	1											0.707834	10								
12	3															0.707835	10				
12	4																	0.707825	11		
12	5																			0.707842	10
13	Mi1																	0.707845	9		
13	Mi2																			0.707958	11
14	Ec1																	0.707876	11		
14	Ec2																			0.707876	10

Boreal samples (first set) for Sr analysis

			Average	S. Er	S Dev.	N=x
NBS-987		1st set	0.710227		21	12
NBS-987		2nd set (normalised)	0.710234		15	11
1		0.707438	0.707451	9	12	3
1		0.707455				
1	*	0.707460				
2		0.707503	0.707504	8	11	3
2		0.707494				
2		0.707516				
3		0.707507	0.707528	13	18	3
3		0.707538				
3		0.707538				
4		0.707568	0.707561	6	9	3
4		0.707566				
4		0.707551				
4	*	0.707581				
5		0.707573	0.707574	1	2	3
5		0.707572				
5		0.707576				
6		0.707568	0.707570	4	6	3
6		0.707567				
6		0.707565				
6	*	0.707578				
7		0.707662	0.707653	7	12	4
7		0.707640				
7		0.707662				
7	*	0.707646				
8		0.707694	0.707707	7	12	4
8		0.707710				
8		0.707703				
8	*	0.707720				
9		0.707623	0.707638	12	17	3
9		0.707633				
9		0.707657				
10		0.707751	0.707742	4	7	4
10		0.707734				
10		0.707742				
10	*	0.707740				
11		0.707729	0.707755	13	18	3
11		0.707768				
11		0.707766				
11	*	0.707757				
12	?	0.707834	0.707875			1
12	?	0.707835				
12	?	0.707825				
12	?	0.707842				
12	*	0.707875				
13		0.707845	0.707899			1
13		0.707958				
13	*	0.707899				
14		0.707876	0.707961			1
14		0.707876				
14	*	0.707961				

Boreal samples (Hemmoor/Kronsmoor, 2nd set) for Sr isotope analysis

Number			location in m	belemnite/brach zone	sample type
Date of run					
Turret no.					
NBS-987=					
NBS-987=					
Loose belemnite repeats					
Bo	1	2	see prev.		
Bo	4	4			
Bo	6	4			
Bo	7	4			
Bo	8	4			
Bo	10	4			
Bo	11	4			
Bo	12	5			
Bo	13	Mi2			
Bo	14	Mi1			
Hemmoor and Kronsmoor belemnite and bulk sediment samples					
Bo	K1	b	7m above base of Maas.	lanceolata/jasmundi-acutirostris (Surlyk, 82)	Belemnite
Bo	K2	b	17m above base of Maas.	obtusa (Schulz, 1979)/ spinosa-subtilis	Belemnite
Bo	K3	b	~25m abover base of Maas.	obtusa (Schulz, 1979)/ spinosa-subtilis (top)	Belemnite
Bo	K4	b	~35m above base of Maas.	sumensis (Schulz, 1979)/ pulchellus-pulchellus	Belemnite
Bo	H5	b	31m below Lower/Upper Maas. boundary	cimbrica/ pulchellus-pulchellus	Belemnite
Bo	H6	mi	10m below Lower-Upper Maas. boundary	fastigata/pulchellus-pulchellus	chalk sediment
Bo	H7	mi	1m above Lower/Upper Maas. boundary	tegulatus-junior (Schulz & Schmid, 1979)	chalk sediment
Bo	H8	mi	10m above L/U Maas. boundary	tegulatus-junior (Schulz & Schmid, 1979)	chalk sediment
Bo	H9	mi	20m above L/U Maas. boundary	tegulatus-junior (Schulz & Schmid, 1979)	chalk sediment
Bo	H10	mi	30m above L/U Maas. boundary	argenta-junior	chalk sediment
Bo	H11	mi	40m above L/U Maas. boundary	argenta-junior	chalk sediment
Bo	H12	mi	50m above L/U Maas. boundary	argenta-junior	chalk sediment
Bo	H13	mi	60m above L/U Maas. boundary	argenta-junior	chalk sediment
Bo	H14	mi	70m above L/U Maas. boundary	baltica-danica	chalk sediment
Bo	H15	mi	80m above L/U Maas. boundary	baltica-danica	chalk sediment

Boreal samples (Hemmoor/Kronsmoor, 2nd set) for Sr isotope analysis

87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -
22.5.90		25.5.90.		27.5.90.		30.5.90.		3.6.90.		5.6.90.		13.6.90.		22.6.90.	
'654 & '655		'657		'658		660 & 661		'662 & 3		'664 & 5		672 & 674		678 & 679	
0.710340	4	?		0.710347	6	?0.710261		0.710376	6	0.710330		0.710335	6	x	
0.710327	4	0.710323	7	0.710299	7	0.707319		0.710307	6	0.710309	5	0.710320	6	0.710312	6
		0.707546	6												
0.707667	4														
0.707664	6														
0.707732	5														
0.707806	5														
0.707826	4														
0.707849	4					0.707837	5								
		0.707961	8												
		0.707985	9												
		0.707961	8												
0.707810	6					0.707837	5					0.707821	6		
0.707909	6					0.707908	5					0.707918	5		
0.707859*	10					0.707828	5					0.707848	7		
0.707872	14					0.707856	5					0.707882	5		
0.707867	6					0.707844	3				6	0.707863	6		
						0.707861	6	0.707888	5	0.707868	5				
						0.707869	5	0.707874	6	0.707872	5				
						0.707901	6	0.707885	6	0.707872	5				
						*0.707903	8	0.707872	5	0.707900	6				
						0.707876	7	0.707874	7	0.707891	4				
								0.707887	5	0.707892		*0.707885	5		
								0.707902	5			0.707893	6	0.707892	6
								0.707909	6			0.707906	5	0.707914	5
								0.707884	4			0.707921	7	0.707891	6
								*0.707956	9			0.707905	4	0.707904	7

Boreal samples (Hemmoor/Kronsmoor, 2nd set) for Sr isotope analysis

									S.Dev	S. Err	
							at NBS-987=0.710319?				at NBS-987=
1	2		0.707546				0.707546	1			0.707460
4	4		0.707667				0.707667	1			0.707581
6	4		0.707664				0.707664	1			0.707578
7	4		0.707732				0.707732	1			0.707646
8	4		0.707806				0.707806	1			0.707720
10	4		0.707826				0.707826	1			0.707740
11	4	0.707837	0.707849				0.707843	1			0.707757
12	5	0.707961					0.707961	1			0.707875
13	Mi2	0.707985					0.707985	1			0.707899
14	Mi1	0.707961					0.707961	1			0.707875
K1	b			0.707837	0.707810	0.707821	0.707823	3	14	10	0.707737
K2	b			0.707908	0.707909	0.707918	0.707912	3	6	4	0.707826
K3	b			0.707828	0.707859*	0.707848	0.707845	3	16	11	0.707759
K4	b			0.707856	0.707872	0.707882	0.707870	3	13	9	0.707784
H5	b			0.707844	0.707867	0.707863	0.707858	3	12	9	0.707772
H6	mi	0.707868	0.707888	0.707861			0.707872	3	14	10	0.707786
H7	mi	0.707872	0.707874	0.707869			0.707872	3	3	2	0.707786
H8	mi	0.707872	0.707885	0.707901			0.707879	3	15	10	0.707793
H9	mi	0.707900	0.707872	*0.707903			0.707886	3	17	12	0.707800
H10	mi	0.707891	0.707874	0.707876			0.707883	3	9	7	0.707797
H11	mi	0.707892	0.707887			*0.707885	0.707886	3	4	3	0.707800
H12	mi		0.707902		0.707892	0.707893	0.707895	3	6	4	0.707809
H13	mi		0.707909		0.707914	0.707906	0.707910	3	4	3	0.707824
H14	mi		0.707884		0.707891	0.707921	0.707899	3	14	10	0.707813
H15	mi		*0.707956		0.707904	0.707905	0.707922	3	30	21	0.707836

Sr-isotope results for M. Jouf, N.Italy

Locality		Spe	Subc	Hand spec. description	I.R. %	Acid for dissol.		
						HCl	HCl	Acetic
						2.5M	0.25M	5 M
J	19	K1	Ca1	Katzeria, well preserved	0	8		
J	19	K1	Ca2	Katzeria, well preserved	0	3		
J	19	K1	Ca3	Katzeria, well preserved	0	4		
J	19	K1	Ca4	Katzeria, well preserved	0	7		
J	19	K1	Ar1	Katzeria	0	3		
J	19	K1	MI1	org-rich C-A pkst	5			3
J	19	K1	MI2	org-rich C-A pkst	0		3	
J	19	K2	Ca1	Katzeria, not so well preserved	0	3		
J	19	K2	Ca2	Katzeria, not so well preserved	0	3		
J	19	K2	MI2	org-rich C-A	10			
J	25	d	MI1	foram. C-A	0		6	
J	25	d	MI2	foram. C-A	0		6	
J	25	2	a	Radiolitid, perfect polyg. cells		x		
J	25	2	b,I	Radiolitid, perfect polyg. cells		x		
J	25	2	b,II	Radiolitid, perfect polyg. cells		x		
J	25	2	b,III	Radiolitid, perfect polyg. cells		x		
J	25	2	b,Iv	Radiolitid, perfect polyg. cells		x		
J	25	2	Ce1	cement in cavity in sed (birds eye?), small	0	3		
J	25	2	MI1	white C-A	2		5	
J	25	2	MI2	white C-A	1		4	
J	26	1	Ce1	cement in sed (birds eye?)	0	3		
J	26	1	Ce2	cement in sed (birds eye?)	0	3		
J	26	1	MI1	white C-A	1		5	
J	26	1	MI2	white C-A	0		4	
J	26	4	MI1	C-A	1		7	
J	26	4	MI2	C-A	2		5	
J	26	X1		Small thin Rads., ?cells, v. hard pkst matrix		x		
J	26	X1	MI1	C-A + some shelly material	75			3
J	26	X1	MI2	C-A + some shelly material	0		5	
J	26	X2	a	Small thin Rads., ?cells, v. hard pkst matrix		x		
J	26	X2	b	Small thin Rads., ?cells, v. hard pkst matrix		x		
J	30	4		B. excavata, cells, karstified ?		x		
J	31-32	3		lamellar calcite in rock		x		
J	32	1	a	B. excavata, ?cells		x		
J	32	1	bI	B. excavata, ?cells		x		
J	32	1	bII	B. excavata, ?cells		x		
J	32	1	bIII	B. excavata, ?cells		x		
J	32	1	bIv	B. excavata, ?cells		x		
J	33	1	a	B. excavata, ?cells		x		
J	33	1	bI	B. excavata, ?cells		x		
J	33	1	bII	B. excavata, ?cells		x		
J	33	1	bIII	B. excavata, ?cells		x		
J	33	1	bIv	B. excavata, ?cells		x		
J	34	S2	I	Requienid, Apricardia, brown calcite		x		
J	34	S2	II	Requienid, Apricardia, brown calcite		x		
J	34	S2	III	Requienid, Apricardia, brown calcite		x		
J	34	S2	Iv	Requienid, Apricardia, brown calcite		x		
J	34	S2	v	Requienid, Apricardia, brown calcite		x		
J	34	S3		Joufia, thick lamellar debris in middle of slide		x		
J	34	S3	MI1	C-A, one with much shell material	0			4
J	34	S3	MI2	C-A, one with much shell material	0		3	
J	34	S4	I	Outer Joufia layer, lamellar, perfect optical pres		x		
J	34	S4	II	Outer Joufia layer, lamellar		x		
J	34	S4	III	Outer Joufia layer, lamellar		x		
J	34	S4	Iv	Outer Joufia layer, lamellar		x		
J	34	S4	v	Outer Joufia layer, lamellar		x		
J	34	S4	Ar1	recrystallised coral	0	3		
J	34	S4	Ar2	recrystallised coral	0	3		
J	34	S4	MI1	C-A chalky with shelly frags	0			5
J	34	S4	MI2	C-A chalky with shelly frags	0		3	
J	34	S6		Outer Joufia layer, lamellar		x		
J	34	4		Small hipps. karstified on outside		x		
J	42	?	a	Large Rad with cells but not obvious. bored		x		
J	42	?	bI	Large Rad with cells but not obvious. bored		x		
J	42	?	bII	Large Rad with cells but not obvious. bored		x		
J	42	?	bIII	Large Rad with cells but not obvious. bored		x		
J	42	?	bIv	Large Rad with cells but not obvious. bored		x		
J	42	13	b	Large Rad, middle layer		x		
J	42	X4	I	Colveraia, outer layer, lamellar well pres.		x		
J	42	X4	II	Colveraia, outer layer, lamellar well pres.		x		
J	42	X4	III	Colveraia, outer layer, lamellar well pres.		x		
J	42	X4	Iv	Colveraia, outer layer, lamellar well pres.		x		
J	42	X4	v	Colveraia, outer layer, lamellar well pres.		x		
J	42	X6	a,I	Joufia debris, lamellar, slightly neomorph.		x		
J	42	X6	a,III	Joufia debris, lamellar, slightly neomorph.		x		
J	42	X6	a,Iv	Joufia debris, lamellar, slightly neomorph.		x		
J	42	X6	a,v	Joufia debris, lamellar, slightly neomorph.		x		
J	42	X6	b 1	Joufia debris, another bit		x		
J	42	X6	b 2	Joufia debris, another bit		x		
J	42	X6	b 3	Joufia debris, another bit		x		
J	42	X6	b 4	Joufia debris, another bit		x		
J	42	X6	b 5	Joufia debris, another bit		x		
J	42	X6	MI1	white foraminiferal grainstone	0			4
J	42	X6	MI2	white foraminiferal grainstone	0		3	
J	45	4b		Apricardia, as used before				

Sr-isotope results for M. Jouf, N.Italy

Locality		Spec	Subd	87/86 Sr	+ / -	87/86 Sr	+ / -		+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -
				17.2.89.		25.2.89.		27.2.89.		4.3.89.		1.3.89.	
						'346		'348		'352		'350	
		NBS-987		0.710259	11	0.710215	9	0.710214	10	0.710226	9	0.710226	10
				0.710257	10					0.710248	10		
J	19	K1	Ca1										
J	19	K1	Ca2										
J	19	K1	Ca3										
J	19	K1	Ca4										
J	19	K1	Ar1										
J	19	K1	MI1										
J	19	K1	MI2										
J	19	K2	Ca1										
J	19	K2	Ca2										
J	19	K2	MI2										
J	25	d	MI1										
J	25	d	MI2										
J	25	2	a	0.707709	10								
J	25	2	b,I	0.707630	9								
J	25	2	b,II			0.707549	10						
J	25	2	b,III			*0.707607	27						
J	25	2	b,Iv			0.707539	15						
J	25	2	Ce1										
J	25	2	MI1										
J	25	2	MI2										
J	26	1	Ce1										
J	26	1	Ce2										
J	26	1	MI1										
J	26	1	MI2										
J	26	4	MI1										
J	26	4	MI2										
J	26	X1		0.707616	10								
J	26	X1	MI1										
J	26	X1	MI2										
J	26	X2	a	0.707649	8								
J	26	X2	b	*0.707681	16								
J	30	4		0.707687	12								
J	31	3				0.707709	11						
J	32	1	a										
J	32	1	bi										
J	32	1	bii										
J	32	1	biii										
J	32	1	biv										
J	33	1	a			0.707679	12						
J	33	1	bi			0.707694	11						
J	33	1	bii			0.707665	8						
J	33	1	biii					0.707648	10				
J	33	1	biv	0.707824	10								
J	34	S2	I									0.707684	10
J	34	S2	II									0.707685	10
J	34	S2	III									0.707669	10
J	34	S2	Iv									0.707672	12
J	34	S2	v									0.707692	10
J	34	S3											
J	34	S3	MI1										
J	34	S3	MI2										
J	34	S4	I									0.707654	12
J	34	S4	II					0.707676	9				
J	34	S4	III					0.707678	10				
J	34	S4	Iv					0.707693	10				
J	34	S4	v					0.707654	10				
J	34	S4	Ar1										
J	34	S4	Ar2										
J	34	S4	MI1										
J	34	S4	MI2										
J	34	S6											
J	34	4											
J	42	?	a							0.707853	11		
J	42	?	bI							0.707705	9		
J	42	?	bii							0.707673	12		
J	42	?	biii							0.707694	12		
J	42	?	biv							0.707689	9		
J	42	13	b										
J	42	X4	I							0.707716	10		
J	42	X4	II							0.707738	10		
J	42	X4	III							0.707690	10		
J	42	X4	Iv							0.707728	10		
J	42	X4	v							0.707689	9		
J	42	X6	a,I										
J	42	X6	a,III			0.707717	16						
J	42	X6	a,iv			0.707701	10						
J	42	X6	a,v			0.707771	10	0.707713	10				
J	42	X6	b 1			0.707711	9						
J	42	X6	b 2					0.707743	10				
J	42	X6	b 3										
J	42	X6	b 4									0.707693	9
J	42	X6	b 5										
J	42	X6	MI1										
J	42	X6	MI2										
J	45	4b								0.707683	10		

Sr-isotope results for M. Jouf, N.Italy

	Spec	Sub	87/86 Sr	+/	87/86Sr	+/	87/86Sr	+/	87/86Sr	+/	87/86Sr	+/	87/86Sr	+/
			12.3.89.		27.5.89.		4.6.89.		22.6.89.		23.6.		25.6.89	
			'358 & 359		'406		'412		'423		'424		'425	
	NBS-98		0.710217	10	0.710250	10	0.710240	10	0.710241	10	0.710229	10	0.710231	11
			0.710225	10	0.710200	11					0.710220	11	0.710218	11
19	K1	Ca1			0.707455	10								
19	K1	Ca2			0.707479	11								
19	K1	Ca3			0.707482	10								
19	K1	Ca4			0.707479	10								
19	K1	Ar1			0.707573	10								
19	K1	MI1					0.707545	10						
19	K1	MI2					0.707492	12						
19	K2	Ca1			0.707464	11								
19	K2	Ca2					0.707510	10						
19	K2	MI2												
25	d	MI1							0.707566	10				
25	d	MI2							0.707610	12				
25	2	a												
25	2	b,I												
25	2	b,II												
25	2	b,III												
25	2	b,iv												
25	2	Ce1									0.707671	10		
25	2	MI1							0.707614	44				
25	2	MI2							0.707645	16				
26	1	Ce1									0.707657	17		
26	1	Ce2									0.707697	10		
26	1	MI1							0.707642	11				
26	1	MI2							0.707635	10				
26	4	MI1							0.707695	10				
26	4	MI2							0.707623	10				
26	X1													
26	X1	MI1					0.707649	10						
26	X1	MI2					0.707591	11						
26	X2	a												
26	X2	b												
30	4													
31	3													
32	1	a	0.707664	11										
32	1	bI	0.707717	11										
32	1	bII	0.707657	10										
32	1	bIII	0.707686	8										
32	1	biv	*0.708206	11										
33	1	a												
33	1	bI												
33	1	bII												
33	1	bIII												
33	1	biv												
34	S2	I												
34	S2	II												
34	S2	III												
34	S2	Iv												
34	S2	v												
34	S3		0.707686	9										
34	S3	MI1					0.707682	10						
34	S3	MI2					0.707682	7						
34	S4	I												
34	S4	II												
34	S4	III												
34	S4	Iv												
34	S4	v												
34	S4	Ar1											0.707703	10
34	S4	Ar2											0.707702	10
34	S4	MI1					0.707704	10						
34	S4	MI2					0.707707	9						
34	S6		0.707691	10										
34	4		0.707668	10										
42	?	a												
42	?	bI												
42	?	bII												
42	?	bIII												
42	?	biv												
42	13	b	0.707669	12										
42	X4	I												
42	X4	II												
42	X4	III												
42	X4	Iv												
42	X4	v												
42	X6	a,I	0.707699	10										
42	X6	a,III												
42	X6	a,Iv												
42	X6	a,v												
42	X6	b 1												
42	X6	b 2												
42	X6	b 3												
42	X6	b 4												
42	X6	b 5	0.707757	10										
42	X6	MI1					0.707657	10						
42	X6	MI2					0.707717	6						
45	4b													

Sr-isotope results for M. Jouf, N.Italy

87/86Sr	+ / -		Strat. ht.						
30.6.89				*= result not used in calculation of average value					
*429						Mean	Std err.	Std dev	N=x
*0.710185	11								
				NBS-987		0.710230		17	17
		0.707455	124	k1c1		0.707489	10	27	9
		0.707479	124	k1c2					
		0.707482	124	k1c3					
		0.707479	124	k1c4					
		0.707573	124	k1a1	*				
		0.707545	124	k1m1					
		0.707492	124	k1m2					
		0.707464	124	k2c1					
		0.707510	124	k2c2					
0.707494	11	0.707494	124	k2m2					
		0.707566	275	25dm1		0.707603	16	44	9
		0.707610	275	25dm2					
		0.707709	275	252a	*				
		0.707630	275	252bI					
		0.707549	275	252bII					
		*0.707607	275	252bIII					
		0.707539	275	252biv					
		0.707671	275	252c1					
		*0.707614	275	252m1					
		0.707645	275	252m2					
		0.707657	362	261c1	*				
		0.707697	362	261c2	*				
		0.707642	362	261m1		0.707637	11	32	9
		0.707635	362	261m2					
		0.707695	362	264m1					
		0.707623	362	264m2					
		0.707616	362	26x1					
		0.707649	362	26x1m1					
		0.707591	362	26x1m2					
		0.707649	362	26x2a					
		0.707681	362	26x2b					
		0.707687	432	304					
		0.707709	464	313					
		0.707664	465	321a		0.707680	8	24	11
		0.707717	465	321bI					
		0.707657	465	321bII					
		0.707686	465	321bIII					
		0.708206	465	321biv					
		0.707679	467	331a					
		0.707694	467	331bI					
		0.707665	467	331bII					
		0.707648	467	331bIII					
		0.707824	467	331biv	*				
		0.707684	467	34s2I		0.707684	4	15	17
		0.707685	467	34s2ii					
		0.707869	467	34s2III					
		0.707672	467	34s2iv					
		0.707692	467	34s2v					
		0.707686	467	34s3					
		0.707682	467	34s3m1					
		0.707682	467	34s3m2					
		0.707654	467	34s4I					
		0.707676	467	34s4II					
		0.707678	467	34s4III					
		0.707693	467	34s4iv					
		0.707654	467	34s4v					
		0.707703	467	34s4a1	*				
		0.707702	467	34s4a2	*				
		0.707704	467	34s4m1					
		0.707707	467	34s4m2					
		0.707691	467	34s6					
		0.707668	467	344					
		0.707653	508	42?a		0.707705	6	26	21
		0.707705	508	42?bI					
		0.707673	508	42?bII					
		0.707694	508	42?bIII					
		0.707689	508	42?biv					
		0.707669	508	4213b					
		0.707716	508	42x4I					
		0.707738	508	42x4II					
		0.707690	508	42x4III					
		0.707728	508	42x4iv					
		0.707689	508	42x4v					
		0.707699	508	42x6aI					
		0.707717	508	42x6aIII					
		0.707701	508	42x6aiv					
		0.707713	508	42x6av					
		0.707711	508	42x6b1					
		0.707713	508	42x6b2					
		0.707743	508	42x6b3					
		0.707693	508	42x6b4					
		0.707757	508	42x6b5					
		0.707657	508	42x6mI1					
		0.707717	508	42x6mi2					
		0.707683	508	454b					

Yugoslavian samples for isotope analysis

No.	No.	No.	No.	Sample description	unit	%	2.5M	0.25M	5MAce	No.	No.	No.	87/86Sr	+ / -
			Nanos Mnt.									Nanos M	17.12,544	
													0.710245	10
													0.710207	11
YS	20	4	KaCa?1	altered calcite	L. Maas. K.terg.			5		20	4	KaCa?1		
YS	20	4	KaCa?2	altered calcite	L. Maas. K.terg.				4	20	4	KaCa?2	0.707489	10
YS	20	4	KbCa1	Reasonable	L. Maas. K.terg.	18.2		6		20	4	KbCa1		
YS	20	4	KbCa2	Reasonable	L. Maas. K.terg.	2.9			8	20	4	KbCa2		
YS	20	4	KbAr1		L. Maas. K.terg.		3			20	4	KbAr1		
YS	20	4	KbAr2		L. Maas. K.terg.		4			20	4	KbAr2		
YS	20	2	H1	Hipp and Rad growing together. should be hipp	massive lst, few rudists		3			20	2	H1	0.707734	10
YS	20	2	H2	Hipp and Rad growing together. should be hipp	massive lst, few rudists			3		20	2	H2		
YS	20	2	Ca1	Brachiopod	massive lst, few rudists		2			20	2	Ca1		
YS	20	2	Ca2	Brachiopod	massive lst, few rudists			3		20	2	Ca2	0.708022	11
YS	20	2	Ce1	cement infill to top of brach	massive lst, few rudists		3			20	2	Ce1	0.707713	10
YS	20	2	Ce2	cement infill to top of brach	massive lst, few rudists		4			20	2	Ce2		
YS	20	2	Mi1	sed infill to bottom	massive lst, few rudists			3		20	2	Mi1		
YS	20	2	Mi2	sed infill to bottom	massive lst, few rudists				5	20	2	Mi2		
YS	20	1	b1	algal laminite	U. Maas above rudist lst	3.3		4		20	1	b1		
YS	20	1	b2	algal laminite	U. Maas above rudist lst	4.3			5	20	1	b2	0.707717	8
YS	32	3	Mi1	sediment with R. liburnica	U. Maas bed 47			3		32	3	Mi1		
YS	32	3	Mi2	sediment with R. liburnica	U. Maas bed 47	2.6			4	32	3	Mi2		
YS	32	1	Ca1	Radiolitid	U. Maas. immed beneath bed 45			3		32	1	Ca1		
YS	32	1	Ca2	Radiolitid	U. Maas. immed beneath bed 45				3	32	1	Ca2		
YS	32	1	Ar1	Radiolitid	U. Maas. immed beneath bed 45		2			32	1	Ar1		
YS	32	1	Ar2	Radiolitid	U. Maas. immed beneath bed 45		2			32	1	Ar2		
YS	32	1	Mi1	Radiolitids and requienids in bitumenous matrix	U. Maas. immed beneath bed 45	10.8		5		32	1	Mi1		
YS	32	1	Mi2	Radiolltids and requienids in bitumenous matrix	U. Maas. immed beneath bed 45				3	32	1	Mi2		
YS	32	6	Mi1	Scaglia Rossa	Palaeocene	5.1		4		32	6	Mi1		

Yugoslavian samples for isotope analysis

87/86Sr	+ / -	87/86Sr	+ / -	87/86Sr	+ / -	87/86Sr	+ / -	87/86Sr	+ / -		No	No.	No.			
18.11,545		6.1,559		30.1.90.		4.2.90.		22.6.90.					Nanos	Mnt.		
				'576		'581		'678 & 9		norm.				Final		
0.710234	7	0.710233	11	0.710241	7	0.710208	11	x							NBS-987	0.710227
0.710245	10	0.710237	11	0.710233	7	0.710188	11	0.710312	6						Strat ht	mean
0.707525	10			x							20	4	KaCa?1	0.707525	Nanos	
											20	4	KaCa?2	0.707489	10	0.707497
0.707487	9										20	4	KbCa1	0.707487	55	0.707707
		0.707487	8								20	4	KbCa2	0.707487	D. Vas	
		0.707508	10								20	4	KbAr1	0.707508	5	0.707778
0.707524	9										20	4	KbAr2	0.707524	11	0.707803
				0.707744	10						20	2	H1	0.707739		
0.707703	10			0.707736	13						20	2	H2	0.707720		
0.707767	8			x							20	2	Ca1	0.707767		
				0.707755	11						20	2	Ca2	0.707879	1	0.707497
											20	2	Ce1	0.707713	2	0.707707
0.707659	11										20	2	Ce2	0.707659	3	0.707778
0.707722	10										20	2	Mi1	0.707722	4	0.707803
		0.707707	10	0.707684	10						20	2	Mi2	0.707696		
0.707689	11										20	1	b1	0.707689		
				0.707723	10						20	1	b2	0.707720		
											Dolenja Vas					
		0.707780	9					0.707868	6		32	3	Mi1	0.707780		
						0.707729	12	0.707912	6		32	3	Mi2	0.707776		
		0.707828	10					0.707987	5		32	1	Ca1	0.707898		
0.707782	10							0.707958	7		32	1	Ca2	0.707869		
		0.707983	13					0.708090	5		32	1	Ar1	0.707992		
0.707876	10										32	1	Ar2	0.707876		
0.707742	9							0.707893	6		32	1	Mi1	0.707804		
						0.707803	11				32	1	Mi2	0.707803		
								0.707834	4		32	6	Mi1	0.707745		

Samples from Montsech (first set) for Sr isotope analysis

Locality	Spec. no	Rudist	Specimen description	Sample nar
				NBS-987
P314	35.315	*H. vidali*	good calcite, some silicification	314
P20	2.462	*H. variabilis*	mostly silicified	20
P333	36.737	*H. ?vidali*	colour banding, some sil.	333
P347		*Hippurites*	grey calcite	347Htes
P347		*Hippuritella*	grey calcite	347HIIa
P348		*Biradiolites*	pinky. cellular layer bored	348
P22	2.662	*Praeradiolites subtoucasi*	pinky. beautiful cells	22(622)
P22	2.663	*Praeradiolites subtoucasi*	cells and compact layers. marl filling	22(623)
P349		*? radiolitid*	lamellar layer. much iron oxide coating	349
P345		*Agerostrea ungulata*	flaky calcite	345
P344		*rad. indet.*	excellent cells	344Rad
P344		*Apricardia sicoris ?*	dark brown calcite	344Ap
P343		*Apricardia sicoris ?*	possibly recrystallised	343Ap
P343		*Hippuritella lapeirousei*	patches of spar in outer shell. must be bored. orange	343HIIa
P343		*Praeradiolites boucheroni*	irregular sparry voids bet layers	343Pr
P25	2.645	*?Praeradiolites ?boucheroni*	excellent cells in reddish lump	245 ?
P74		*Monopleura moroi*	parts of thin shell were recrystallised	74
P75		*"Radiolites"(=Agriopleura) moroi*	taken from inside layer which looked more compact, a	75
P76	3.086	*Biradiolites chaperi*	reasonable cells, but a bit sparry, not adj. 1	76
P30	2.575	*Praeradiolites boucheroni*	good cells, not adj. 1	30
P298		*"Radiolites"(=Agriopleura) moroi*	looks compact, not cellular, some iron oxide, not adj 1	298
P299		*Praeradiolites boucheroni*	good cells, Fe-rich layers in colour banding, not adj	299
P71		*"Hippuritella" castroi*	beautiful, adj 1	71

Samples from Montsech (first set) for Sr isotope analysis

Sample nar	87/86 Sr	+ / -	87/86 Sr	26.5.88.	+ / -	3.7.88.	+ /	22.11.88	+ /	31.1.89.	+ /	1.2.89.	+ / -	3.2.89.	+ / -
	17.5.88. old		to new m	'224		'242		'302		'334		'335		'336	
NBS-987	0.710191		(x .7102	0.710240		0.710185	13	0.707233	9	0.710232	9	0.710207	16	x	
						0.710143	13							0.710193	11
314	0.707529	13	0.707570	0.707564	34							0.707551	19		
20	0.707552	13	0.707602	0.707577	38							0.707652	15		
333	0.707495	25	0.707545	0.707571	27							0.707551	10		
347Htes				0.707679	23							0.707648	10		
347Hlla	0.707540	17	0.707590	0.707640	14							0.707679	11		
348	0.707622	26	0.707672	0.707726	20							0.707739	10		
22(622)				0.707623	27									0.707627	19
22(623)				0.707654	23									0.707612	13
349				0.708206	46									x	
345				0.707700	16									0.707698	6
344Rad				0.707736	26									0.707766	13
344Ap				0.707694	30									0.707683	9
343Ap						0.707810	13	0.707673	13	0.707773	13				
343Hlla						x		0.707879	10	0.707864	14				
343Pr						x		0.707749	12	0.707793	13				
245 ?						0.708042	29	0.707877	11	0.707947	26				
74						0.708042	29	0.707755	10	x					
75						x		0.707790	10	0.707782	10		182	180	402
76						0.707769	11			0.707932	20				
30						0.707807	20			0.707886	9				
298						x		0.707785	11	0.707856	13				
299						0.707786	10			0.707761	10				
71						0.707708	13			0.707768	10				

Samples from Montsech (first set) for Sr isotope analysis

Heigh	Sample name	87/86 plott	Trace element concs.			
			Fe	Mn	Sr	Al
900	314	0.707558	-	-	-	
900	20	0.707615	74	15	1210	18
900	333	0.707561	41	5	1599	8
995	347Htes	0.707664	98	11	924	6
995	347Hlla	0.707660	242	18	685	9
1040	348	0.707733	182	19	353	19
1060	22(622)	0.707625	66	8	921	9
1060	22(623)	0.707633	30	4	1247	3
1150	349	x	121	96	532	952
1200	345	0.707699	1150	78	290	7
1285	344Rad	0.707751	-	-	-	
1285	344Ap	0.707689	97	10	1113	10
1320	343Ap	0.707723	-	17	1212	22
1320	343Hlla	0.707872	1150	78	290	7
1320	343Pr	0.707771	630	42	606	8
1490	245 ?	0.707912	-	-	-	
1702	74	0.707755	1045	108	231	34
1706	75	0.707786	948	151	892	12
1742	76	0.707932	1320	352	873	10
1726	30	0.707886	1172	261	582	10
1706	298	0.707821	292	78	1203	4
1702	299	0.707761	182	180	402	34
1790	71	0.707768	479	45	1261	2

Samples from Montsech (second set) for Sr isotope analysis

	No.	No.	Sample description	2.5H	0.25H	5MAc	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -
							26.6.89.		25.6.89.		30.6.89.		1.7.89.		18.7.89.	
							'424		'425		'429		'430		'435	
							0.710212	11	0.710231	11	*0.710185	11	0.710234	11	0.710231	10
									0.710218	11						
S	347 Htes	Ca1		2					0.707618	11						
S	347 Htes	Ca2		4					0.707675	12						
S	347 Htes	Ar1		2					0.707685	10						
S	347 Htes	Ar2		2					0.707656	9						
S	347 Htes	Mi1	fine brown			5										
S	347 Htes	Mi2	fine brown		3						0.707597	12				
S	347 HIIa	Ca1		2					0.707598	11						
S	347 HIIa	Ar1		2					0.707674	36					0.707709	10
S	347 HIIa	Mi1	brown C-A			4										
S	298	Ca1		2									0.707746	10		
S	298	Ca2		2									0.707736	10		
S	298	Ar1		2									*			
S	298	Ar2		2									0.708086	11		
S	298	Mi1				3										
S	298	Mi2			3								0.707799	10		
S	299	Ca1	cells	2									0.707758	9		
S	299	Ca2	cells	3					0.707769	10						
S	299	Ar1		4					*0.707805	41					0.707798	10
S	299	Ar2		2					0.707938	10						
S	299	Mi1	goethite-rich coarse C-A			3										
S	299	Mi2	goethite-rich coarse C-A		3		0.707790	11								
S	75	Ca1		3			0.707741	9								
S	75	Ca2		3			0.707767	10								
S	75	Ar1		2			0.707969	10								
S	75	Ar2		2			x								0.708072	12

Samples from Montsech (second set) for Sr isotope analysis

87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -
23.10.89.		24.10.89.		24.10.89.		5.11.89.	
'507		'508		'512		'516	
*0.710197	10	0.710235	11	0.710250	10	0.710186	10
*0.710190	11	0.710202	9	0.710211	8	0.710240	10
				0.707659	9		
0.707664	10						
		0.707774	11				

Combined results for Montsech

	F	G	H	I	J	K	L
1	Strat h	mean	N=x	N=x	N=x	Std err	Std dev
2			1st set	2nd set	3rd set		32.08
3	NBS-98	0.710221	5				20
4	NBS-98	0.710225	5				9.6
5	900	0.707578	3				33.18
6	995	0.707643	2	3			
7	1050	0.707681	1				
8	1200	0.707699	1				
9	1285	0.707720	2				
10	1320	0.707747	2				
11	1704	0.707772		6			13.85
12	1790	0.707783	1		5		17.06
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							

Samples from French Pyrenees

	No.			87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	Final
				4.2.90.		10.2.90.		25.5.90.		27.5.90.		5.6.90.		8.6.90.		result at
				'581		'587		'657		'658		'664 & '665		'667		0.710233
				0.710208	11	*0.710163	10	x		0.710347	6	0.710230	7	x		
				*0.710188	11	*0.710181	10	0.710323	7	0.710299	7	0.710309	5	0.710323	6	
F	Au	1	Ca1											0.707973	4	0.707887
F	Au	1	Ca2							0.707980	7					0.707894
F	Au	1	Ar1	0.707897	10											0.707897
F	Au	1	Ar2	0.707876	10			x								0.707876
F	Au	3	Ca2							0.707972	4					0.707886
F	Au	3	Mi1											0.707925	5	0.707839
F	Au	4	Ca1											0.707933	6	0.707847
F	Au	4	Ca2							0.707967	5					0.707881
F	Tr	1	Ca1											0.707880	5	0.707794
F	Tr	1	Ca2													0.707764
F	Tr	1	Ar1			0.707774	10	0.707850	5							0.707774
F	Bo	1	Ca1											0.707883	5	0.707797
F	Bo	1	Ca2							*0.707873	5			0.707886	4	0.707800
F	Bo	1	Ar1			0.707894	7	x				0.707972	7	0.707861	4	0.707852
F	Bo	2	Ca2							0.707867	4					0.707781
F	Bo	2	Ar1											0.707855	5	0.707769
F	Bo	3	Ca2							0.707960	8					0.707874

Bulgarian samples for Sr isotope analysis

Specimen			Sample	Specimen description	Sample description	% I.R.	Acid for dissolution			87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -
				from thin section	from chip in binocular microscope		HCl	HCl	Acetic	26.6.89. '424		28.6.89. '428		30.6.89. '429		18.7.89. '435		21.7.89. '438		30.8.89 '464	
							2.5M	0.25M	5M	0.710212	11			*0.710185	11	0.710221	11	0.710223	11		
																0.710231	10				
Garlo, Breznik																					
B	B	X1	Ca1	Neoradiolites	thin-walled polygonal cells	0	3														
B	B	X1	Ca3	Neoradiolites	thin-walled polygonal cells	0			2												
B	B	X1	Ar1	Neoradiolites	yellow and bitty	0	2														
B	B	X1	Ar2	Neoradiolites	yellow and bitty	0	2														
B	B	X1	Mi1	Neoradiolites	some recrystallised calcite	58		3													
B	B	X1	Mi2	Neoradiolites	some recrystallised calcite	56			3												
B	B	X3	Ca1	fragment with poly. cells	doesn't look cellular	0	3														
B	B	X3	Ca2	fragment with poly. cells	doesn't look cellular	0			2												
B	B	X3	Mi1	Grey coarse C-A	grey	52		3													
B	B	X3	Mi2	Grey coarse C-A	grey	66			3												
B	B	X4	Ca1	large radiolitid	well preserved cells	0	4														
B	B	X4	Ca2	large radiolitid	well preserved cells	0	3														
B	B	X4	Ca4	large radiolitid	well preserved cells	24			3												
B	B	28a	Ca1	compact calcite	well preserved	0	2													0.707547	12
B	B	28a	Ca2	compact calcite	well preserved	0	3													0.707554	10
B	B	28a	Ca3	compact calcite	well preserved	0	3													0.707536	10
B	B	28a	Mi1	sediment	looks more like calcite	90		3													
B	B	25x	Ca2	bivalve	very well preserved, dk brown	0	3														
B	B	25x	Ca3	bivalve	very well preserved, dk brown	0	3														
Yaroslavtzi, Breznik																					
B	B	28X1	Ca1	Hippurites heritschi	some black dots	9	2			0.707540	10										
B	B	28X1	Ca2	Hippurites heritschi	some black dots	5	3							0.707519							
B	B	28X1	Ca3	Hippurites heritschi	some black dots	7	3							0.707508	10						
B	B	28X1	Ar1	Hippurites heritschi	iron staining	0	4					0.706745	9								
B	B	28X1	Ar2	Hippurites heritschi	iron staining	0	2							0.707092	10						
B	B	28X2	Ca2	Vaccinites loftusi	calcite	0	3											0.707583	10		
B	B	28X2	Ca3	Vaccinites loftusi	calcite	0	3											0.707549	10		
B	B	28X2	Ar1	Vaccinites loftusi	recrystallised aragonite	0	2											0.707399	10		
B	B	28X2	Ar2	Vaccinites loftusi	recrystallised aragonite	0	4											0.707225	10		
B	B	28X2	Mi1	Vaccinites loftusi	fine grey marl	62		3													
B	B	28X2	Mi2	Vaccinites loftusi	fine grey marl	73			3												
B	B	28c	Ca1	oyster	well preserved lamellar calcite	0	2									0.707667	10			0.707621	10
B	B	28c	Ca2	oyster	well preserved lamellar calcite	0	2									0.707632	10				
B	B	28c	Ca3	oyster	well preserved lamellar calcite	0	2									0.707621	10				
Yambol																					
B	Y	1	Ca1	Vaccinites	long. cells	0	3														
B	Y	1	Ca2	Vaccinites	long. cells	0	3														
B	Y	1	Ca3	Vaccinites	long. cells	0	3														
B	Y	1	Ca4	Vaccinites	long. cells	0	3														
B	Y	1	Ar1	Vaccinites	completely clear single crystal																
B	Y	1	Ar2	Vaccinites	completely clear single crystal	0	3														
B	Y	2	CaCe2		rectangular cells	16			3												
B	Y	2	Mi2		grey, one with orange vein	0			3												

Bulgarian samples for Sr isotope analysis

87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	87/86 Sr	+ / -	Specimen No.			Sample No.					
30.9.89.		24.10.89.		29.10.89		5.11.89.		19.11.89.		27.11.89		30.1.90										
'487		'508		'512		'516		'528		'535		'576										
0.710209		0.710235	11	0.710250	10	0.710186	10	0.710197	10	0.710219	11	0.710241	7				*=used in average		mean	Std err	Std dev	N=x
0.710194		0.710202	9	0.710211	8	0.710240	10	0.710187	10	0.710184	11	0.710233	7				NBS-987		0.710212		22	20
										0.710180	11											
				0.707251	11									B	X1	Ca1	0.707251					
						0.707259	10							B	X1	Ca3	0.707259					
		0.707176	9											B	X1	Ar1	0.707176					
				0.707258	10									B	X1	Ar2	0.707258					
						0.707383	10							B	X1	Mi1	0.707383					
		0.707496	9											B	X1	Mi2	0.707496					
				0.707427	9									B	X3	Ca1	0.707427					
						0.707447	10							B	X3	Ca2	0.707447					
				0.707530										B	X3	Mi1	0.707530					
		0.707357	10											B	X3	Mi2	0.707357					
						0.707507	10							B	X4	Ca1	0.707507	*	0.707504	3	5.2	3
										*0.707498	9			B	X4	Ca2	0.707498	*				
								0.707507	10					B	X4	Ca4	0.707507	*				
														B	28a	Ca1	0.707547	*	0.707546	5	9.1	3
														B	28a	Ca2	0.707554	*				
														B	28a	Ca3	0.707536	*				
								0.707436	10					B	28a	Mi1	0.707436					
										0.707532	10			B	25x	Ca2	0.707532	*	0.707533			2
0.707534	11													B	25x	Ca3	0.707534	*				
														B	28X1	Ca1	0.707540	*	0.707540	13	29.1	5
														B	28X1	Ca2	0.707519	*				
														B	28X1	Ca3	0.707508	*				
														B	28X1	Ar1	0.706745					
														B	28X1	Ar2	0.707092					
														B	28X2	Ca2	0.707583	*				
														B	28X2	Ca3	0.707549	*				
														B	28X2	Ar1	0.707399					
														B	28X2	Ar2	0.707225					
								0.706770	10					B	28X2	Mi1	0.706770					
										0.706798	10			B	28X2	Mi2	0.706798					
														B	28c	Ca1	0.707640	*	0.707631	6	9.5	3
														B	28c	Ca2	0.707632	*				
														B	28c	Ca3	0.707621	*				
0.707740	11							0.707692	8			0.707726	11	Y	1	Ca1	0.707719	*	0.707734	9	15	3
0.707655	10									0.707696	11	0.707697	5	Y	1	Ca2	0.707669					
0.707769	10											0.707729	10	Y	1	Ca3	0.707749	*				
0.707746	11									0.707724	10			Y	1	Ca4	0.707735	*				
0.706306	10													Y	1	Ar1	0.706306					
										0.706344	11			Y	1	Ar2	0.706344					
										0.707341	11			Y	2	CaCa2	0.707341					
								0.707337	10					Y	2	Mi2	0.707337					

10 (2)

The Platform carbonates of Monte Jouf, Maniago, and the Upper Cretaceous stratigraphy of the Italian Carnian Prealps

N.H.M. Swinburne, The Open University, Walton Hall, Milton Keynes, MK7 6AA, ENGLAND

A. Noacco, Via Reghena 14, 33170 Pordenone, ITALY

The Platform carbonates of Monte Jouf, Maniago, and the Upper Cretaceous stratigraphy of the Italian Carnian Prealps

N.H.M. Swinburne, The Open University, Walton Hall, Milton Keynes, MK7 6AA, ENGLAND

A. Noacco, Via Reghena 14, 33170 Pordenone, ITALY

Abstract

The paper provides a detailed description of the Upper Cretaceous stratigraphy of a part of the alpine foothills, north of Udine, near to the town of Maniago in northern Italy. We present a detailed geological map of the M. Jouf area showing the structure of an elongate domal anticline cut by large E-W reverse faults and thrusted at the base. The limestones, which are part of the Calcari del Monte Cavallo, are described and determinations made on the faunas of rudist bivalves and benthic foraminifera. M. Jouf is the original locality of two genera of rudists *Joufia* and *Colveraia* which are important biostratigraphic markers in Tethys and we comment on the type locality. The limestone sequence has been subdivided into 4 units on the basis of facies and these have been dated using Sr-isotope chronology. This technique gives an independent age for the age the units and also of some of the more widely-used biostratigraphic markers as they occur on M. Jouf. It thus provides an accurate and precise timescale to present the evolution of the palaeoenvironment in this part of the Adriatic Carbonate Platform. We note two main epochs of broad, shallow carbonate platforms, covered by a diverse rudist fauna with large individuals, including recumbent forms. The first of these was in the Late Cenomanian and the second in the latest Campanian. The Late Cenomanian event was ended by a regression which lead to the emersion of the platform margins and then by a transgression which drowned the platform. Sediment wedges then began to build out again over the Late Cenomanian deposits, though in the interval Turonian-Santonian sediment by-passed the M. Jouf area. In the latest Campanian platform carbonate deposition was ended by a regression. Faulting at various times in the Maastrichtian and early Tertiary finally lead to the break up of the Platform.

In the foothills of the Alps, as they rise abruptly from beneath the cover of the Venetian plain in northern Italy, there are several outcrops of Cretaceous limestones. These limestones, now forming the Carnian Prealps, were deposited on the north-western edge of the carbonate platform which includes the rocks exposed today on the Yugoslavian coast. The westernmost part of the outcrop makes up the Monte Cavallo-Cansiglio mountain range (fig. 1). This is continuous with the M. Fara - M. Jouf - M. San Lorenzo massif which is the subject of this paper. To the east, and separated by an area of Tertiary rocks, is M. Ciaurlec as well as a few outcrops on M.Pala and M. Prat. East of these is the river Tagliamento which marks the boundary between the Carnian and Julian Alps.

The areas have much in common in structure and stratigraphy. The Cretaceous and Tertiary rocks are delimited to the north by the major Periadriatic overthrust (Dainelli, 1921; Zenari, 1929) which brings Jurassic and Triassic rocks southwards and marks the start of the Alps proper. The general form of the Cretaceous outcrops is exemplified by M. Jouf, which is an asymmetric, domal anticline with a gently sloping northern limb, folded sharply into a steeply-dipping, occasionally overturned, southern limb. The entire mass has also been thrust southwards (Martinis, 1979). To the north and east of M. Jouf, the structure closes in a synclinal basin. Here the Cretaceous limestones are overlain by Tertiary deposits, firstly red-grey marls, the so-called Scaglia Rossa, then dark-grey sandstones and siltstones, the Flysch, and finally by continental conglomerates (fig. 4c).

The area is of particular interest because it was believed to be one one of the few places in Italy where the platform carbonates were still being deposited at the very end of the Cretaceous Period (Philip, 1985). Indeed, M. Jouf is known from the literature to be the type locality of two genera of rudist bivalves, *Joufia* and *Colveraia* , described at the turn of the century (Boehm, 1898; Klinghardt, 1921), and conventionally regarded as Maastrichtian in age (Sladić-Trifunović, 1987).

This study is based on detailed logging of the Upper Cretaceous carbonates exposed on the road sections on M. Jouf, a collection of the rudist faunas and dating of the sequence using strontium isotope chronology (a detailed discussion of which will be the subject of a future paper), by N.H.M. Swinburne; mapping of the area at a scale of 1:5000 and broader study of the limestone stratigraphy and facies over the entire M.Fara - M.Jouf - M. San Lorenzo area by A. Noacco.

Outcrop on Monte Fara, Monte Jouf and Monte San Lorenzo

The M. Fara - M. Jouf - M. San Lorenzo limestone massif has several sharply incised N/S valleys which potentially provide excellent exposure of the sequence, particularly of its lower parts (see fig. 1 for location map). That of Val Cellina, to the west of M. Fara marks the western limit of this study. Val Cellina cuts a section roughly perpendicular to the SW-NE trending axis of the M. Fara part of the anticline. At the mouth of Val Cellina, on the road to Montereale Val Cellina, at Ravedis, there is an excellent view of the anticline structure with the tight folding in the anticline core and the assumption of the regular northerly dip of around 25°, seen along the gorge to the north. However, the apparent simplicity is sometimes deceptive as there are undoubtedly several low-angled thrusts hidden amidst the seemingly homogeneous limestone sequence, noteably the duplexes visible in the southern part of the Val Cellina (fig. 2). The Cretaceous limestones pass up into the Tertiary Scaglia Rossa and then Flysch in the core of the Barcis-Andreis syncline north of the junction between the Torrente Cellina and the Torrente Alba. The Cretaceous limestone then reoccurs in a thin fault slice, north of Lake Barcis.

M. Jouf is bordered to the east by Val Colvera which separates it from M. San Lorenzo. Parts of M. San Lorenzo are intensely fractured and these zones have been quarried to such an extent that the mountain summit has been partly removed. From the exposures in these quarries Martinis (1979) has shown that there may be a thrust fault at the base of the anticline on its

southern side, located mainly along the junction between the Cretaceous limestones and the Scaglia Rossa.

The upper parts of the Cretaceous limestone sequence are best seen on M. Jouf itself. Exposure is available along a track some 20 years old, which leads from Maniago to the summit, and a new road which leads north from the summit down to the pass at Pala Barzana. The southern side of the anticline is generally patchily exposed and outcrops are difficult to correlate. It is also more faulted that the northern side and two main trends can be detected: a N-S subvertical set and an E-W set with northerly dipping component. The northern part of the anticline, which begins about half way up the southern side of the mountain, is easier to study although there are still some areas of non-exposure and occasional tilted blocks. Outcrop along the northern road is extensive but as the road runs approximately parallel to bedding the oucrop is of limited stratigraphic extent. The northern limb is also cut by small N-S faults, probably of little throw.

Previous work

The sequence of Val Cellina has been the focus of previous attention to this limestone massif. Most important are the works of Zenari,1929 (who compiled the first major geological map of the Maniago area); Ferasin,1958, Cuvillier *et al.*,1968; Gnaccolini & Mattavelli,1969; Salvini, 1969, and more recently Ghetti,1986 and Noacco,1987. Recent work on M. Jouf is restricted to the study of Saint-Marc, 1963 who recorded the sucession from Ravedis, via Val di San Antonio and finishing at Pala Barzana. Noacco, 1987 presents the first major published account of the Val Colvera sequence. There are also several papers concentrating on the tectonic structure of this zone such as: Dainelli, 1921; Martinis, 1966, 1979; Zanferrari, 1973, 1974. Previous descriptions of the Upper Cretaceous rudist fauna of the Carnian Prealps can be found in: Pirona, 1877, 1884; Tellini, 1892; Boehm 1894, 1897, 1898; Zenari, 1920 and Klinghardt, 1921.

Stratigraphic Units

The limestone has traditionally been divided into three formations called the Calcari del Cellina (Oxfordian - Aptian), Calcari del Monte Cavallo (?Albian - Campanian/Maastrichtian) and the Calcari di Andreis (U. Palaeocene). These names were never formally defined but were used in the geological surveys of the area by AGIP (AGIP, 1959) and have been adopted by subsequent authors. In this paper we divide the Calcari del Monte Cavallo, as it outcrops on M. Jouf, into 4 subunits: Unit 1, Upper Cenomanian; Unit 2, lower-middle Campanian; Unit 3, middle Campanian-uppermost Campanian; Unit 4, uppermost Campanian. The units have been dated using both the available biostratigraphic indicators of benthic foraminifera and rudist bivalves and also the Sr-isotopes preserved in the rudist shells (for details, see fig. 5). Fig. 2 shows the location of the unit boundaries on the road sections of M. Jouf and the locality numbers referred to in the text. Figure 3 is a geological map of the M. Jouf and its surroundings and figure 4 a stratigraphic column.

Calcari del Cellina

The Calcari del Cellina, which ranges only into the lower Cretaceous is beyond the scope of this discussion and the reader is referred to the works of Cuvillier *et al.* ,1968., Masse & Sentenac, 1987. In general these sediments are characteristic of extremely shallow water and have numerous palaeosol horizons indicating emergence. They also differ from those of the overlying formation in being poorer in macrofossils, notably rudist bivalves.

Calcari del Monte Cavallo

The base of the Calcari del M. Cavallo can not be seen on M.Jouf, where the earliest rocks belong to the Upper Cenomanian. In Val Cellina, the lowest subdivision of this unit was considered Albian-Cenomanian by Cuvillier *et al.*, 1968 and by Saint-Marc, 1963. However, studies on M. Cavallo-Cansiglio revealed a major lacuna between deposits of Albian age and

those of Upper Cenomanian (Sartorio, 1987) and from Albian to Lower Campanian (Masse & Sentenac, 1987).

The outcrop of the base of the Calcari del Monte Cavallo in Val Colvera (near to the 2.2 km sign) is described by Noacco, 1987. There are abundant small, pipe-like, bouquet-forming radiolitids in bioherms orientated at a slight angle to bedding, or lying horizontally in biostromes. These are interbedded with white limestones containing caprinid debris, palaeosols and intraformational conglomerates some 70cm thick, particularly concentrated near the top of this interval. The rudist beds are overlain by some 12m of grey and pink non-fossiliferous dolomitised micrites and followed by the conglomerates.

Unit 1: Upper Cenomanian

The top of the unit described from Val Colvera has a small exposure on M. Jouf in the anticline core, where it was studied in greater detail. At 930 m (J17) there are many small thin-walled, dark brown reqieniids (probably *Apricardia*) as well as radiolitids. The sediments are pel- and forambiomicrites or sparites mostly packstones-grainstones containing textulariids and miliolines in varying proportions. There is also some wackestone with rotalines and sponge spicules. Sometimes the sediment is a gravel made of intraclasts of different varieties of these facies. The environment represented seems to be of a frequently disturbed inner shelf where reworking is common in shallow water.

The age of this outcrop is well constrained from the foraminifera. The following genera and species were noted** : *Nezzazatinella* sp. ?*Nezzazatinella simplex* (Omara), *Cuneolina* sp., *Pseudolituonella (aff. reicheli?), Rotalia* aff. *mesogeensis* Tronchetti, *Trochospira avnimelechi* Hamaoui & St. Marc, which strongly suggest a Cenomanian age, and most probably Upper Cenomanian (Bilotte, Pers. Comm.) for the unit as exposed on M.Jouf.

An isolated outcrop slightly higher on the mountain, at 1020-1035 m, (J22iv & 23) is thought to be the same age, though is of different facies. The outcrop is discordant to general bedding, and is probably a thrust slice from near the core of the anticline. At J23 the limestone is chalky-white and contains a large caprinid, *Caprinula boissyi* d'Orbigny and a radiolitid, probably *Radiolites*. Specimens of the caprinid lie parallel to bedding planes in a sediment probably similar to that in which they lived. This is an intraclastal gravel of forambiomicrite wackestones and packstones, rich in miliolines and also containing dasycladacean algae and gastropods. The immediately overlying beds contain caprinid debris and palaesol horizons. At the adjacent outcrop of J22 iv there are a few very well developed palaeosol horizons about 20 cm in thickness and irregularly discordant to the general bedding direction. These contain variegated clayey intraclasts in a white clayey matrix. In section the clasts show laminoid fenestrae with geopetal fills, fragments of dasycladacean algae, coated echinoderm plates and ostracods with fringing cements. The matrix is sometimes rich in ostracod shells. All indications are of a very shallow water shoal environment of the middle platform, which periodically emerged.

C. boissyi was recorded by Klinghardt, 1921 from M. Jouf. The same species is also known from other places in Yugoslavia and Italy (see illustration in Iannone & Laviano,1980 and references therein) from strata assigned ages ranging from Cenomanian to Middle Turonian although the Turonian dates are now considered less reliable (Masse & Philip, 1986).

Unit 2: lower Campanian - middle Campanian

This unit includes rocks exposed south of the anticline core at heights 850-890m (J16, 15, 15b and 19) as well as the beds on the northern side of the core, from 970-1110m (J22i, ii, iii, v, 24, 25 & J26). South of the anticline core the limestone is well-bedded (0.5-1m thick). The beds are mainly biostromes and debris beds and more rarely, bioherms, of small pipe-like radiolitids, probably *Bournonia* and *Medeella* and rarer *Katzeria* . The rudists, which can not easily be separated from the limestone sediment are best observed on weathered blocks where

they may be iron-stained (as are the larger milioline foraminifera) and stand out from the sediment. The sediments have varying amounts of rudist debris and are forampelmicrite, packstones-grainstones (with prominent miliolines), and biosparite grainstones (with well preserved textulariids). Rarely there are horizons with fenestrae or large dolomite-filled vugs and these beds may also contain planktonic forams. This shows that even parts of the platform under such shallow water still received sporadic pelagic sedimentation. The radiolitids must have been growing in small thickets of the low energy inner platform and have merely been knocked over and scarcely transported.

North of the anticline core, the corresponding beds are slightly different in lithology and represent shallower conditions. The lowest unit is whitish in colour and an intraclastal gravel of pelsparite and pelmicrite grainstone-packstone (the peloids are probably mostly micritised foraminifera) It contains gastropods and various bivalves, long lamellar rudist fragments as well as some entire specimens of *Durania* sp. and a small and a large species of hippuritid.

There then follow beds similar to those at J15, 16, with biostromes and debris beds (J22iii) and from there on (J22ii, 22i, 21, 24, 25, 26) the sequence shows progressively fewer rudist-rich beds and the beds thin to an average of 0.5m or less. The most abundant sediment is a forambiomicrite packstone-grainstone with textularids and prominent miliolines. Algal laminites made of an interlamination of pelbiosparite grainstone and wackstone, which includes some planktonic foraminifera, become more common. The beds are frequently divided by stylolites. At the top of this unit (J25) there are also very flat beds with birds eyes and pink dolomitised horizons. These facies are cyclical in nature and finish with intraformational conglomerate which marks the completion of a minor marine regression (fig 6). A small radiolitid appears at the top of the facies. It has several irregular projections, a relatively thin wall, no ligamentary invagination and therefore was either a species of *Bournonia* , or of *Biradiolites* .

The age of this unit is not well constrained from the biostratigraphy. The hippuritid, from J22v gives the best evidence for the age of the base of the unit. Sections of the two specimens are undoubtedly similar to that figured by Pleničar as *Vaccinites* aff.*giganteus* d'Hombres-firmas from the Coniacian-Santonian of M. Nanos, Yugoslavia (Pleničar, 1975), although that figure does not resemble the original description. Incidently another specimen *V.* aff.*giganteus* was found on the south shore of Lake Barcis on the new road to Cansiglio (Val Caltea). Several other large hippuritids have also been noted from this locality (Saint-Marc, 1963; Ghetti, 1986). The specimens of *Katzeria* are also of some help in biostratigraphy. This genus is known from the Karst of Yugoslavia mostly from beds of Senonian (ie. Coniacian-Maastrichtian) age (Pleničar, 1973, 74).

Beds south of the anticline core also yielded the foraminifera: *Montcharmontia apenninica* (De Castro) and *Cuneolina* aff. *pavonia* which suggest an age Santonian-Campanian. The dates from the foraminifera at J22iii, near the base of this unit, but north of the core, are vaguer with aff. *Stensiöina surrentina* Torre, and aff. *Abrardia mosae* (Hofker), suggesting Campanian - Maastrichtian.

The Sr-isotope measurement on the *Vaccinites* at 22v gave an ill-defined age of lowermost Campanian, though specimens from Val Caltea, which were better preserved, gave well constrained dates in the middle of the Campanian. *Katzeria* made suitable material for Sr-isotope dating and gave an age of lower Campanian. The numerous measurements on samples at J25 &J26 give a precise age for the top of the unit in the middle of the Campanian.

Unit 3: middle Campanian - upperCampanian

The change in facies at 1110m (between J26 & J27) is marked by the reappearance of densely-packed rudist biostromes, which are more thickly bedded (1-3m). In these, one species predominates, the small radiolitid with two prominent wings *Bournonia excavata* d'Orbigny.

B.excavata replaces a very similar radiolitid present at the top of the previous unit . The boundary between the two units is marked by a small fault on the road.

B. excavata occurs in biostromes and debris beds and fragments constitute a major proportion of the sediment. In some beds it is accompanied by a small species of the genus *Pseudopolyconites*, mostly broken and sometimes only represented by numerous spines. The sediment is a pelbiosparite or forambiosparite grainstone with well preserved textulariids and miliolines, though when the pellets have been pressed together and degraded the sediment may resemble a biomicrite wackestone. Dasycladacean algae are fairly common in this facies. There are irregular calcite-filled vugs and dolomitization is extensive. This all indicates a shallow environment, generally subtidal and well oxygenerated, in shoals such as might exist in moderate energy environments of the middle platform.

B. excavata is of mild biostratigraphic use as it is recorded from the Santonian - Maastrichtian of Slovenia (Polšak & Mamuzić, 1969). Most species of *Pseudopolyconites* are regarded as Maastrichtian in Yugoslavia but one species may extend down into the Coniacian (Pejović & Sladić-Trifunović, 1977). The foraminifera are again less diagnostic with *Cuneolina* sp. (*pavonia-parva* Henson)?, aff. *Stensiöina surrentina, Tetraminouxia* aff. *gibbosa* Gendrot and *Moncharmontia apenninica* which collectively indicate Coniacian-Campanian.

Unit 4: uppermost Campanian

The junction of units 3 and 4 is marked by an intraformational conglomerate and about a metre of deposits which record a rapid deepening of the water (fig. 7). Unit 4 is widely exposed on the northern side of M. Jouf and contains a numerous and diverse fauna of large radiolitids: *Joufia reticulata* Boehm, *Colveraia variabilis* Klinghardt, *Pseudopolyconites* sp. 2, the smaller radiolitids *Sauvagesia* sp. and *Katzeria* (which is almost certainly a radiolitid, despite its acellular appearance); hippuritids: *Pironaea polystyla* Pirona *var. forojuliensis* and *Hippurites lapeirousei* Goldfuss; as well as the enigmatic canaliculate recumbent rudist

"Sabinia" aniensis Parona (spelt *anienis* by Parona, though misspelt by subsequent authors as *aniensis*), the Plagioptychid (*sensu* Skelton, 1978) *Plagioptychus* sp. and requieniid *Apricardia sp.*. Where the rock is not intensively fractured it breaks into cobbles or boulders, the bedding is difficult to see but the fauna is readily collectable. The sediments are grainstones with some packstones and are generally coarser than previous unit, sometimes reaching rudite grade. They are made of rudist fragments, echinoderm plates, micritised orbitoids with rare planktonic foraminifera. The environment represented must have been one in fairly turbulent waters at the shelf edge.

There is some noticeable variation inside the unit which is lateral as much as vertical, although this is difficult to assess given the nature of the outcrop. A unit of coarse grainstone made almost entirely from echinoid spines overlies the lowest beds of rudist limestone. The bed, which probably wedges out laterally and is not more than 5-10m thick and represents a shallow shoal. The middle of the unit is also barren of macrofauna; bedding is well developed and the sediments are predominantly intertidal laminated pelmicrite packstones-wackstones with some desiccation cracks. The friable appearance of some outcrops also suggests some carbonate dissolution, probably penecontemporaneous. After this interval the rudist limestones reappear and these are cut by several horizons of laminated greeny clay. These are probably penecontemporaneous as in section the lamination can be seen to follow original lithological changes.

Exposures at the top of the sequence as the road nears the pass of Pala Barzana contain some noteworthy biostromes. There is a large thicket of the small bouquet-forming hippuritid, *Hippurites lapeirousei* Goldfuss, embedded in a muddy sediment. Adjacent to the hippuritids were found several individuals of a large species of *Pseudopolyconites*, in life position, and surrounded by halos of spines which nearly interlocked. Each spine is about 1mm in external diameter and curves downwards after exiting the shell. The same bed also had specimens of *Sabinia anienis* lying flat, parallel to the bedding, and some disarticulated and sometimes broken valves of *Joufia*. The co-occurrence of *Pseudopolyconites* with its hairy spines which

best served to baffle sediment, together with the stable shape of the recumbent *Sabinia* is significant. It confirms suggestions of Skelton & Gili (in press) that both had adopted strategies for maximum stability which allowed them to live in shoal areas washed by currents.

The exposures on northern M. Jouf near Pala Barzana are, as already indicated, quite new and the rudists described by other authors come from other localities. Böhm first described the genus *Joufia* from the top part of two free valves which he collected after a walk across the top of M. Jouf (Böhm, 1898). Klinghardt, 1921 collected a much larger amount of material (13 large chests to be precise!) and from these specimens amended and added to Böhm's description of *Joufia* and named the genus *Colveraia.* We located Klinghardt's original locality which is a disused quarry, on the Torrente Colvera di Jouf (see fig. 1). Beds dip steeply downwards at this location and the quarry is filled with loose blocks from all horizons in units 3 and 4.

As regards the age of the uppermost unit of the platform carbonates, it contains many genera of rudists (*Joufia, Colveraia, Sabinia, Pironaea, Pseudopolyconites*), which have traditionally been regarded as Maastrichtian. This age assignment is traced ultimately to the work of Milovanović (1934, 1960) from eastern Serbia where the uppermost beds of platform carbonate, which also contained *Pironaea* were collectively termed Maastrichtian. They were then subdivided into three zones of purported lower, middle and upper Maastrichtian according to the supposed evolutionary development of *Pironaea.* Thus *Pironaea*, and the co-occuring rudist genera, gained a reputation as Maastrichtian (Sladić-Trifunović, 1972, 1980, 1981, 1983, 1987). The *Pironaea* from M. Jouf, called *P. polystyla forojuliensis* by Klinghardt, under that scheme would be Middle Maastrichtian in age. Unfortuntely the scheme has now been shown to be invalid as the variation can be ontogenetic (Pons & Vicens, presentation at the 1988 Rudist Conference, held in Belgrade). In recent years outcrops with the same rudist assemblage dated using independent criteria, notably the benthic foraminifera, have been considered somewhat older than Maastrichtian, eg. Campanian (probably lower Campanian) on the island of Brac, Croatia, Yugoslavia (Pejović & Radoičić, 1987), or by using Sr-

isotopes and benthic foraminifera, middle Campanian at Garlo, Brezhik (Swinburne, unpublished data).

There were a few recognisable foraminifera from this unit on M. Jouf : aff. *Reticulinella* cf. *reicheli* (Cuvillier *et al.*), *Moncharmontia apennica* , but most usefully,*Siderolites* cf. *vidali* (according to Bilotte, a Campanian species). However, recognisable orbitoids are more abundant and better preserved in this unit as it outcrops on M. San Lorenzo. The unit there contains the same rudists, albeit in smaller numbers, and is probably of slightly more open marine facies. Species of *Orbitoides* (*O.Tissoti* ??), *Siderolites, Lepitorbitoides* and the smaller benthic *Goupillaudina* were present and these indicate a Campanian-Maastrichtian age, probably Campanian. Saint-Marc, 1963 cites *Orbitoides media, Siplorbites* sp., *Lepidorbitoides* sp. and *Siderolites calcitrapoides* from this unit on M. Jouf, the latter generally regarded as Maastrichtian in age.

There was an abundance of suitable material for Sr-dating. The bottom of the facies thus gave a date near the end of the Campanian and the top slightly below the Boreal the Campanian/Maastrichtian boundary. The top of a unit with very similar assemblage from M.Nanos, Yugoslavia was also dated as near the Boreal Campanian/Maastrichtian boundary.

Calcari di Andreis: Upper Palaeocene

This unit is of interest to the present discussion in consideration of the extent of the stratigraphic gap between the last beds of platform carbonate, and the overlying sediments. This lacuna is significant in the information it yields about the evolution of the environment in this area between the Mesozoic and Cainozoic eras. On the road section of M. Jouf, the uppermost unit of Cretaceous limestone ends with a shattered zone which is one of the well-marked N/S faults, and is followed by around 100m of the breccia of the Calcari di Andreis. This megabreccia is made of beds of limestone blocks, sometimes graded. The blocks may be quite well rounded and vary in size in different beds from boulders of over a metre in diameter to small pebbles. The lithologies are representative of all the limestone facies exposed on M. Jouf with those of

unit 4 predominating at the base of the unit. Matrix, when present, is a greeny clay. There are also prominent palaeokarst horizons irregularly dissect the beds and blocks.

The unit has yielded fragments of foraminifera of both Cretaceous and Tertiary age. Some of the Tertiary forms, such as *Miscellanea miscella* D'Archiac and *Discocyclina* were found at the very base of the unit and this constrains the start of limestone deposition in the Calcari di Andreis to the Palaeocene (and according to Cuvillier *et al.*, 1968, to the Late Palaeocene). The occurence of one of the Cretaceous forms *Hellenocyclina beotica* Reichel is particularly significant. *H. beotica* is indicative of the end of the Maastrichtian in the Pyrenees (Bilotte, Pers. Comm.) and suggests the deposition of a younger unit, not encountered on M. Jouf.

At the top of the breccia at Pala Barzana in the transition to the Scaglia Rossa is a bed of excellently preserved foraminiferal grainstone composed both of Tertiary forms (*Nummulites, Miscellanea miscella*) and reworked Cretaceous examples (*Orbitoides* sp., *Lepidorbitoides*) with clearly eroded margins. The nummulitids and *Discocylina* indicate an minimum age of Late Palaeocene for the Calcari di Andreis at Pala Barzana.

The Calcari di Andreis varies greatly in thickness and in lithology between localities. Whilst there is around 100m of breccia at Pala Barzana, in Val Colvera, at the exit of the tunnel on the new road to Frisanco (locality Fornasatte), there is only about 10m of breccia interbedded with calcarenites. The underlying limestones are well bedded, without the rudist bioherms and contain numerous thin dissolution surfaces - all features indicating a shallower water environment in this area. On the southern side of Lake Barcis, the Calcari di Andreis is made of shallow water limestones, rather than megabreccia. Fragments of nummulitids and alveolinids were also found showing that some of this is Upper Palaeocene. Around M. San Lorenzo, in the quarry on the eastern side, the Calcari di Andreis is exposed in a hillside consisting of a single, steeply-dipping bedding plane. It is made almost exclusively of blocks containing *Sabinia*, encrusted with pyrite cubes. It was almost certainly the lateral equivalent of this surface which Saint-Marc, 1963 (p 806-807) referred to as a hard ground. In the related

deposits of southern Italy Borgomano & Philip, 1987 claim to have detected an ecological preference for *Sabinia* clusters to grow on the upper parts of the slope area which is why they were therefore common amongst blocks of talus.

The Calcari di Andreis debris flows are classic deposits of a bye-pass margin. The platform edge has been downfaulted with some exposure of the tilted blocks and talus collected in an apron around the platform edge. The onset of faulting was probably sometime in the Maastrichtian.

Stratigraphical comparisons with other works

The biostratigraphical subdivisions of the Upper Cretaceous limestones of the Carnian Prealps and their index fossils, as defined by previous authors, have been tabulated in fig. 8. We have attempted to correlate these schemes both to each other and to that used in this study. The schemes reveal two possible lacunae of Turonian - Santonian and Maastrichtian strata.

Turonian-Santonian

One inconsistency between this and previous studies is in the apparent absence on Monte Jouf of strata belonging to the Turonian to Santonian interval. However, because of the lack of exposure and the strong possibility of emplacement of slices in the anticline core by thrust faulting, we can not prove conclusively that such strata were not deposited. Certainly the core of the anticline is made of Upper Cenomanian beds (as dated by foraminiferal biostratigraphy) and this outcrop is accompanied by a fault slice slightly higher on the mountain containing caprinid rudists of probable Late Cenomanian age. The next exposure above this is of rocks with the large hippuritids, dated by Sr-isotopes as Early Campanian by a comparison of the Sr-isotopes to the Boreal stratigraphy, though these are perhaps more properly called Santonian, using Tethyan schemes.

The same caprinid beds are noted in all three of the tabulated biostratigraphic studies from M. Jouf, Val Cellina and M. Ciaulec. They are also noted as the uppermost unit exposed on M. Cavallo by Sartorio (1986, 87). None of the studies presents conclusive evidence that the overlying strata represent Turonian or Coniacian deposits. However, without further research in those regions then the suggestion of a stratigraphic gap in this interval remains speculative.

Maastrichtian

The evidence for this second lacuna on Monte Jouf is much less ambiguous. The top of the rudist beds on Monte Jouf gave a well-constrained Sr-isotope date slightly below the Campanian-Maastrichtian boundary. As the same beds containing rudists and orbitoids, are recorded in all the biostratigraphic schemes, it seems probable that the sequence of platform carbonates terminates at approximately the same level over the entire area. Overlying the limestone, at least on the northern side of the M. Jouf anticline, is a megabreccia of eroded limestone blocks deposited in Late Palaeocene times. This seems to be roughly contemporaneous to the earliest beds of Scaglia Rossa judging from the foraminifera and the inter-fingering of breccia and Scaglia Rossa at localities on M. San Lorenzo. Yet the amount of time which goes unrecorded in the interval between the top of the Cretaceous limestone and bottom of the Tertiary Calcari di Andreis and Scaglia Rossa depends also on the thickness of limestone eroded away, and this varies locally. Somewhere near M. Jouf foraminiferal limestones were being deposited in the Maastrichtian which were the source for some of the blocks in the breccia.

East of M. Jouf on M. Ciaurlec the sequence (as described in Cousin, 1963a) seems very similar to that observed on M. Jouf. However, at some isolated, thrust-bounded oucrops which now lie to the south of M. Ciaurlec at Paveon, and on M. Covria (outcrops mentioned in Cousin, 1963a) the lowest beds of Scaglia Rossa contain such planktonic foraminifera as *Globotruncana arca, G. contusa-calciformis, G. cf. stuarti-stuartiformis* which are Lower Maastrichtian forms. At the southwestern end of Lake Barcis, at the junction of Val Caltea,

Saint-Marc recorded Lower Palaeocene foraminifera from the lowest part of the Scaglia (however, the contact with the Cretaceous limestones at this locality is probably tectonic). These outcrops were probably deposited on areas of the platform which were already submerged due to faulting sooner than M. Jouf.

At other places, which presumably represent more internal parts of the platform, limestone deposition continued for longer. These localities include M. Pedroc, (in Cousin, 1963a) where orbitoid limestones (with *Lepidorbitoides minor* Schlum., *L. socialis* (Leym.), *Siderolites calcitrapoides* Lmk. as well as the purportedly Upper Maastrichtian form *Hellenocyclina beotica*) are overlain by Lower Palaeocene limestones.

Palaeoenvironment of the M. Jouf deposits

The geological evolution of the M. Jouf area is described in figure 9. In Late Cenomanian times broad shelves lay under shallow water and shoal type environments, which periodically emerged, were common. At the end of the Cenomanian, the platform was drowned by a major transgression and sediments began to build out over Upper Cenomanian deposits. In the M. Jouf area strata representing the interval Turonian - Santonian are unrepresented because of by-passing and the first sediments are of early Campanian age. These are representative of a relatively protected, low energy subtidal environment dominated by peloids, small benthic forams and some micrite. As the platform prograded seawards, by middle-late Campanian times the deposits acquired more characteristics of the intertidal zone. At the end of the Campanian there was a slight deepening of water and a return to well washed shoal-type environments, of the platform margin dominated by bioherms of large radiolitids or banks of orbitoids.

Deposition of the rudist limestones came to an end when the sea regressed and withdrew completely from the platform edge leading to non-deposition, and some limestone dissolution during the Maastrichtian stage. On more inner part of the platform very shallow water carbonates contined to be deposited during the Maastrichtian and Early Palaeocene. In Late

Palaeocene the platform margin was broken into fault blocks, the scarps were eroded and talus deposited in the depressions together with pelagic sediment.

A Regional Perspective

Due to alpine tectonics, the M. Jouf area has been compressed in a N-S direction. Thus the transition in facies from platform to slope to basin is difficult to see because the area has been fragmented and telescoped. The Upper Cretaceous deposits found south of the Periadriatic overthust, such as those exposed on M. Jouf, are *in situ* platform carbonates. North of the Periadriatic overthrust, such as Val Cellina north of Lake Barcis (Cousin 1963b), the Upper Cretaceous consists exclusively of pelagic deposits. Slope deposits of Late Cretaceous age are not exposed in this area. This facies transition can however be seen in the Lower Cretaceous deposits of the adjacent M. Cavallo-Cansiglio area (Cousin, 1963a & Masse & Sentenac, 1987), and to the east in the Upper Cretaceous of the Julian prealps (Pirini Radrizzani *et al.*, 1986).

On a regional scale the rocks of the Carnian Prealps are part of a facies belt that curves round to the SE to join the Internal Karst (Postojna mountains). To the south-west of this internal parts of the platform outcrop in the zone of External Karst (Karst mountains). Carbonate platform deposition continued here until the Late Eocene. The Internal Karst is bordered to the north-east by the area of Pre-Karst which was the slope area. This marked the zone of transition between the platform carbonates and the basin facies of the Tolmin trough (Caron & Cousin 1972).The general development of the Adriatic Carbonate Platform is outside the scope of this work and the reader is referred to the reviews of Cousin & Fourcade, 1982; Cavallin & Pirini Radrizzani, 1983.

Conclusions

The Upper Cretaceous strata of M. Jouf are reasonably pure, white limestones and are part of the stratigraphic unit known as the Calcari del Monte Cavallo. On M. Jouf we subdivide this into 4 units.

Unit 1 is Upper Cenomanian, as dated by the caprinid rudist *Caprinula boissyi* d'Orbigny and the small benthic foraminifera *Trochospira avnimelechi* Hamaoui & St. Marc. The sediment is generally an intraclastal gravel of packstones and wackestones and indicative of high energy conditions on a shallow, broad shelf. There is a major unconformity between units 1 & 2.

Unit 2 ranges from the base to the middle of the Campanian according to the Sr-isotope dates. It contains several rudists and benthic foraminifera generally regarded as Senonian (Coniacian-Campanian with or without the Maastrichtian), notably the rudists *Katzeria* , *Vaccinites* aff. *giganteus* , and the foraminifera aff. *Stensiöina surrentina* Torre and aff. *Abrardia mosae* (Hofker). The facies grades from rudist biostromes of probably subtidal origin to a cyclical sub-supratidal plattenkalk.

Unit 3 covers the interval middle-upper Campanian as dated by Sr-isotopes. The Senonian rudists *Bournonia excavata* d'Orbigny and a species of *Pseudopolyconites* are in the upper part of the Campanian at this locality. The sediments are rudist biostromes in a mainly grainstone sediment with other indications of very shallow, but fast-moving water in the middle platform.

Unit 4 is at the very top of the Campanian by correlating the Sr-isotopes to a Boreal Campanian/Maastrichtian boundary (though probably in the Maastrichtian using the planktonic foraminiferal stratigraphy). The dating demonstrates that the assemblage of larger foraminifera - *Orbitoides media, Siderolites calcitrapoides, Leptorbitoides socialis* - and rudists - *Joufia, Colveraia, Pironaea, Pseudopolyconites* usually viewed as Maastrichtian (even Upper

Maastrichtian) may be younger than supposed. The facies is coarser than previous units with an abundance of large rudist and demonstrates turbulent conditions near to the shelf edge.

An unconformity separates the *in situ* rudist limestones from a megabreccia of the Calcari di Andreis and pelagic Scaglia Rossa of Tertiary age. Limestone deposition probably ended due to a regression at the Campanian/Maastrichtian boundary. In Late Palaeocene times the platform margin of the M. Jouf area was extensively down-faulted with erosion of faults scarps and deposition of talus and pelagic deposits on top of the limestones.

Acknowledgments

The M. Jouf work is part of a study by Nicola Swinburne into the extinction of the rudist bivalves at the end of the Cretaceous Period, for a PhD in the years 1987-90, at The Open University, Milton Keynes. This work was supervised by Peter Skelton at the Open University and funded by N.E.R.C. For the other author, Adriano Noacco the work was for a doctoral thesis at the University of Trieste, 1986-88 supervised by Giorgio Longo Salvador, xx. We would also particularly like to thank Michel Bilotte for his identification of the foraminifera from M. Jouf, field assistants Jane Brown and Katherine Medlow for their noble efforts, Peter van Calstren and Mabs Kunka for help with with the Sr-isotope analyses.

Bibliography

AGIP MINERARIA 1959. Microfacies italiane (dal Carbonifero al Miocene medio). S. Donato, Milan.

BÖHM, G. 1894. Beitrag zur Gliederung der Kreide in den Südalpen. I Die Schiosi- und Calleneghe-Fauna. *Zeitschrift der deutschen geologischen Gesellschaft*, **41**, 81-148.

BÖHM, G. 1897. Beitrag zur Gliederung der Kreide in den Venetianer Alpen. *Zeitschrift der deutschen geologischen Gesellschaft*, **49**, 160-181.

BÖHM, G. 1898. Zur Kenntniss der Gattung *Joufia* . *Zeitschrift der deutschen geologischen Gesellschaft*, **50**, 591-592.

BORGOMANO, J. & PHILIP. J. 1987. The rudist carbonate build-ups and the gravitary carbonates of the Gargano-Apulian margin (Southern Italy, Upper Senonian). *Memorie della Società geologica Italiana*, **40**, 125-132.

BURKE, W.H., DENISON, R.E., HETHERINGTON, E.A., KOEPNICK, R.B., NELSON, H.F. & OTTO, J.B. 1982. Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time. *Geology*, **10**, 516-519.

BUSER, S. 1987. Development of the Dinaric and the Julian carbonate platforms and of the intermediate Slovenian basin (NW Yugoslavia). *Memorie della Società geologica Italiana*, **40**, 313-320.

CARON, M. & COUSIN, M. 1972. Le sillon slovène: les formations terrigènes crétacées des unités externes au Nord-Est de Tolmin (Slovénie occidentale). *Bullétin de la Société géologique de France*, **14**(7), 34-45.

CATI, A., SARTORIO, D. & VENTURINI, S. 1987. Carbonate platforms in the subsurface of the northern Adriatic area. *Memorie della Società geologica Italiana*, **40**, 295-308, 2 encl. excl.

CAVALLIN, A. & PIRINI RADRIZZANI, C. 1983. Evoluzione del settore settentrionale della piattaforma carbonatica adriatica. *Rivista italiana di Paleontologia e Stratigrafia*, **89**(2), 223-242.

COUSIN, M. 1963a. Contribution à l'étude géologique des Préalpes carniques orientales (Alpes méridionales, province d'Udine, Italie). *Bullétin de la Société géologique de France*, **5**(7), 809-820.

COUSIN, M. 1963b. Sur la stratigraphie et la paléogéographie du Frioul occidental: Le Val Cellina (Alpes méridionales, Udine Italie). *Bullétin de la Société géologique de France*, **5**(7), 1085-1092.

COUSIN, M. & FOURCADE, E. 1982. Les faciès Crétacés de la plate-forme Frioulano-karstique et leur environnement paléogéographique (Alpes Méridionales et Dinarides). *Cretaceous Research*, **3**, 113-123.

CUVILLIER, J., FOURY, G. & PIGNATTI MORANO, A. 1968. Foraminifères nouveaux du Jurassique superieur du Val Cellina (Frioul Occidental, Italie). *Geologica Romana*, **7**, 141-156.

*DAINELLI, G. 1911. Introduzione allo studio del Cretaceo Friuliano. *Atti della Società Toscana di Scienze Naturale* , **26-27**.

*DAINELLI, G. 1921. La struttura delle Prealpi Friuliane. *Mem. Geogr. G. Dainelli* , Firenze.

FERASIN, F. 1958. Il "Complesso di Scogliera" Cretaceo del Veneto centro-orientale. *Memorie degli Istituti di Geologia e Mineralogia dell'Università di Padova*, **21**, 1-54.

*GHETTI, S. 1986. . *Thesis of the University of Roma*

GNACCOLINI, M. & MATTAVELLI, L. 1969. Esempi di sedimentazione ciclica nella zona interna del complesso di scogliera Barcis-Cansiglio. *Rivista Italiana di Paleontologia e Stratigrafia*, **75**(2), 343-362.

HESS, J., BENDER, M.L. & SCHILLING, J.-G. 1986. Evolution of the ratio of strontium-87 to strontium-86 in seawater from Cretaceous to Present. *Science*, **231**, 979-984.

IANNONE, A. & LAVIANO, A. 1980. Studio stratigrafico e paleoambientale di una successione Cenomaniano-Turoniana (Calcare di Bari) affiorante presso Rivo di Puglia. *Geologica Romana*, **19**, 209-230.

KLINGHARDT, F. 1921a. Die Rudisten. Teil 1: Neue Rudistenfauna aus dem Maastrichtien von Maniago in Friaul, dazu stratigraphischer Anhang. *Archiv für Biontologie*, **5**(1).

KLINGHARDT, F. 1921b. Die Rudisten. Teil IV: Atlas. Selbstverlag, Berlin, Greifswald.

KOEPNICK, R.B., BURKE, W.H., DENISON, R.E., HETHERINGTON, E.A., NELSON, H.F., OTTO, J.B. & WAITE, L.E. 1985. Construction of the seawater 87Sr/86Sr curve for the Cenozoic and Cretaceous: supporting data. *Chemical Geology (Isotope Geoscience Section)*, **58**, 55-81.

LAVIANO, A. & GUARNIERI, G. 1989. *Vaccinites vredenburgi* Kuhn, 1932, from the Upper Cretaceous of Apulia (Southern Italy). *Bollettino della Società Paleontologica Italiana*, **28**(1), 79-86.

MARTINIS, B. 1966. Prove di ampi sovrascorrimenti nelle Prealpi Friuliane e Bellunesi. *Memorie dell'Istituto Geologica e Minerologia dell'Università di Padova* **25**

MARTINIS, B. 1979. La struttura del M. Jouf: un nuovo elemento sovrascorso delle Prealpi Carniche. **65**(6), 313-318.

MASSE, J.-P. & SENTENAC, F. 1987. Variations bathymétriques et instabilité du trefonds: l'exemple des séries carbonatées à sequences loféritiques du Crétacé Inférieur du Frioul (Italie Septentrionale). Signification événementielle dans le cadrd géodynamique de la Méditerranée Occidentale. In: *Salomon , J. (ed.), Transgressions et régressions au Crétacé (France et régions voisines), Mémoires Géologiques du l'Université de Dijon*, **11**, 155-166, Centre des Sciences de la Terre.

MILOVANOVIĆ, B. 1934. Les nouveaux rudistes de la Serbie. I. Serbie orientale, occidentale et Ancienne Raška. Annales Géologiques de la Péninsule Balkanique. **12**, Translated into French in special volume edited by M. Sladić-Trifunović and A. Grubić prepared for The First International Conference on Rudists, held in October 1988 in Belgrade and published by the Serbian Geological Society, Belgrade.

MILOVANOVIĆ, B. 1960. Stratigraphie du Sénonien dans les Dinarides Yougoslaves d'après les rudistes. *Bullétin de la société géologique de France, 7ème série*, **2**, 366-375.

NOACCO, A. 1987. Il passaggio Mesozoico- Tertiario dell'Area di Maniago - Provincia di Pordenone. *Thesis of the University of Trieste.*

PEJOVIĆ, D. & RADOIČIĆ, R. 1987. Contribution to the study of Upper Cretaceous stratigraphy of Brac. *Geologija Razprave in Porocila*, **28/29**, 121-150.

PEJOVIĆ, D. & SLADIĆ-TRIFUNOVIĆ, M. 1977. First occurence of Pseudopolyconites in older Senonian sediments. *Annales Géologiques de la Péninsule Balkanique*, **41**, 175-180.

PHILIP, J. 1985. Sur les relations des marges téthysiennes au Campanien et au Maastrichtien déduites de la distribution des Rudistes. *Bullétin de la Société géologique de France*, **5**(8), 723

PIRINI RADRIZZANI, C., TUNIS, G., VENTURINI, S. 1986. Biostratigrafia e paleogeografia dell'area sud-occidentale dell'anticlinale M. Mia-M. Matajur (Prealpi Giulie). *Rivista Italiana di Paleontologia e Stratigrafia*, **92**(3), 327-382.

*PIRONA, G.A. 1877. Schizzo geologico della provincia di Udine. *Boll. r. com. geol. Italia* , **8**, 114-137.

*PIRONA, G.A. 1884. Nuovi fossili del terreno cretaceo del Friuli. *Mem. r. Ist. Ven. Sc., Let. e Art.*, **22**, 159-168.

PLENIČAR, M 1973. Radiolites from the Cretaceous beds of Slovenia, Part I. *Geologija-Razprave in Poro£cila*, **16**, 187-226. (In Serbo-Croat with English summary).

PLENIČAR, M 1974. Radiolites from the Cretaceous beds of Slovenia, Part II. *Geologija-Razprave in Poro£cila*, **17**, 131-179. (In Serbo-Croat with English summary).

PLENIČAR, M 1975. Hippuritidae of Nanos and the Trieste-Komen Plain. *Academia Scientiarum et Artium Slovenica, Classis IV: Historia Naturalis. Dissertationes*, **18**(4), 1-35, 23 pl. excl. (In Serbo-Croat with English summary).

POLŠAK, A & MAMUŽIĆ, P. 1969. Les nouveaux gisements de rudistes dans le Crétacé supérieur des Dinarides Externes. *Geoloski vjesnik*, **22**, 229-245.

PONS, J.-M. & VICENS, E. in press. Campanian and Maastrichtian rudists from southern Valencia Province, South East Spain. In: *Sladić-Trifunović , M. (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, October, 1988.*

SAINT-MARC, P. 1963. Étude géologique de la région de Barcis (Alpes méridionales, province d'Udine, Italie). *Bullétin de la Société géologique de France*, **5**(7), 803-808.

SALVINI, G. 1969. Osservazioni geologiche sui dintorni di Bàrcis (Prealpi Friuliane). *Rivista Italiana di Paleontologia e Stratigrafia*, **75**(1), 107-121.

SARTORIO, D. 1986. Caprinid patch reef in the Cansiglio inner platform carbonate sequence

(Southern Alps): a record of the earliest Aptian marine transgression. *Rivista Italiana di Paleontologia e Stratigrafia*, **92**(3?), 383-400.

SARTORIO, D. 1987. Reef and open episodes on a carbonate platform margin from Malm to Cenomanian: the Cansiglio example (Southern alps). *Memorie della Società geologica Italiana*, **40**, 91-97, 2 encl. excl.

SKELTON, P.W. 1978. The evolution of functional design in rudists (Hippuritacea) and its taxonomic implications. *Philosophical transactions of the Royal Society of London. Series B.*, **284**, 305-318.

SKELTON, P.W. & GILI, E. (in press). Palaeoecological classification of rudist morphotypes. In: *Sladić-Trifunović, M. (ed.), Proceedings of the First International Conference on Rudists, held in Belgrade, Yugoslavia, October, 1988.*

SLADIĆ-TRIFUNOVIĆ, M. 1972. Senonian limestones with orbitoides and rudists from Kozluk (northeastern Bosnia). *Annales Géologiques de la Péninsule Balkanique*, **37**, 111-150, 13 pl. excl. (In Serbo-Croat with English summary).

SLADIĆ-TRIFUNOVIĆ, M. 1980. Maestrichtian rudists from orbitoid limestones of Pokonji dol on the island of Hvar. *Annales Géologiques de la Péninsule Balkanique*, **43-44,** Beograd.

SLADIĆ-TRIFUNOVIĆ, M. 1983. Palaeontolgical characteristics and biostratigraphic significance of *Pseudopolyconites*. *Annales Géologiques de la Péninsule Balkanique*, **47**, 217-309.

SLADIĆ-TRIFUNOVIĆ, M. 1981. Discovery of *Colveraias* in the Maastrichtian of Yugoslavia (Islands of Brac and Hvar). *Annales Géologiques de la Péninsule Balkanique*, **45**, 221-227.

SLADIĆ-TRIFUNOVIĆ, M. & PEJOVIĆ, D. 1977. A new radiolitid genus from the Senonian sediments of Fundinia (Montenegro) and Povlja (Braƒc island). *Annales Géologiques de la Péninsule Balkanique*, **41**, 221-233. (In Serbo-Croat with English summary).

SLADIĆ-TRIFUNOVIĆ, M. 1987. Pironaea-Pseudopolyconites Senonian of the Apulian plate: palaeobiogeographic correlations and biostratigraphy. **40**, 149-162.

SLIŠKOVIĆ, T. 1967. Biostratigrafija gornje krede juƒzne Hercegovine. *Disertactja Prir.-mat. fakultet, Zagreb.*

TARAMELLI, T. 1881. Spiegazione della carta geologica del Friuli. Pavie.

*TARAMELLI, T. 1877. Catalogo ragionato delle rocce del Friuli. *Atti. Acc. Lincei I*, 546-609.

*TELLINI, A. 1892. Descrizione geologica della tavoletta Majano. *In Alto: Cron. Soc. alpina friul.* **3**, 18-25, 44-48, 76-77, Udine.

ZANFERRARI, A. 1973. Osservazioni geologiche sui terrani attraversati dalle gallerie dell'Autostrada di Alemagn;a presso Vittorio Veneto. Significato dei dati in rapporto alla tettonica del margine meridionale del Cansiglio. *Memorie della Società geologica Italiana*, **12**, 529-548.

ZANFERRARI, A. 1974. Sulla terminazione occidentale del sovrascorrimento periadriatico (piega-faglia peradriatica auct.) nelle Prealpi Carniche. *Bolletino della Società Geologica Italiana*, **93**, 33-46.

*ZENARI, S. 1920. Studio geologico della valle del Torrente Cellina. *Publ. Uff. Idr. Mag. acque Venezia* , **109**, 20pp.

*ZENARI, S. 1929. Note illustrative della Carta Geologica delle Tre Venezie, Foglio "Maniago". *Uff. Idr. R. Mag. Acque Venezia.*

List of figures

Figure 1 Locality map of the M. Fara - M. Jouf - M. San Lorenzo massif with inset showing regional location.

Figure 2 Thrust complexes, or duplexes in southern Val Cellina (in photography)

Figure 3 Locality map of the road sections of M.Jouf showing the position of the unit boundaries and major faults and their proposed stratigraphic correlation

Figure 4 Geological map, cross section and stratigraphic column of the M. Jouf area.

Figure 5 Dating of certain rudist horizons using Sr-isotope chronology. This relies on a comparison of the $87^{Sr}/86^{Sr}$ ratio preserved in a shell of unknown age to a standard graph of $^{87/86}Sr$ change for this period. Figure 5a shows the general pattern of change in 87/86Sr against time for the Upper Cretaceous (data from Koepnick *et al.*, 1985; Hess *et al.*, 1986; Swinburne unpublished). In compiling this "standard graph" it became clear that the various authors had different understandings terms of the use of rock ages in terms of stages and their subdivisions. This study uses the boundaries of the zones as defined by belemnites of the boreal province (Swinburne unpublished) and subdivides the Campanian stage into a lower, middle and upper zone which, if the Sr-isotope ratio change linearly through time, should be zones of approximately equal duration (Figure 5b). Figure 5c shows the variation in $87^{Sr}/86^{Sr}$ with stratigraphic height for the M. Jouf sequence. Error bars on the points show the standard error for that point and the error bar at the side the standard deviation for the NBS-Sr standard, or long term precision (NBS-987=0.71023)

Figure 6: Photos of microfacies

a) J 22iv, base unit 2: Swirling clayey texture of palaeosol. Field of view 3200µm.

b) J 15, unit 2: Foraminiferal (textulariid) grainstone with sparitic matrix (possibly a result of neomorphism. 2 examples of *Montcharmontia apenninica* in upper middle of picture, either side of biserial form. Field of view 5700µm.

c) J 35B, unit 4: Grainstone made almost entirely of echinoid spines. Field of view 5700µm.

d) J 39, unit 4: Algal mat with dessication cracks (cross polars). Field of view 5700µm.

e) J 55, unit 4 (Monte San Lorenzo): Specimen of *Orbitoides* along with spine of the rudist *Pseudopolyconites* . Field of view 5700µm.

f) J 40C, Top of Calcari di Andreis: Bed of reworked Cretaceous foraminifera such as this specimen of *Orbitoides* sp. together with Tertiary forms.

Figure 7 A typical transgression-regression cycle from the top of unit 2.

Figure 8 Correlation of biostratigraphic zonal schemes used by previous authors to that of this study and revision of previous age assignments.

Figure 9 Palaeoenvironmental evolution of the area during Late Cretaceous and Early Tertiary times.

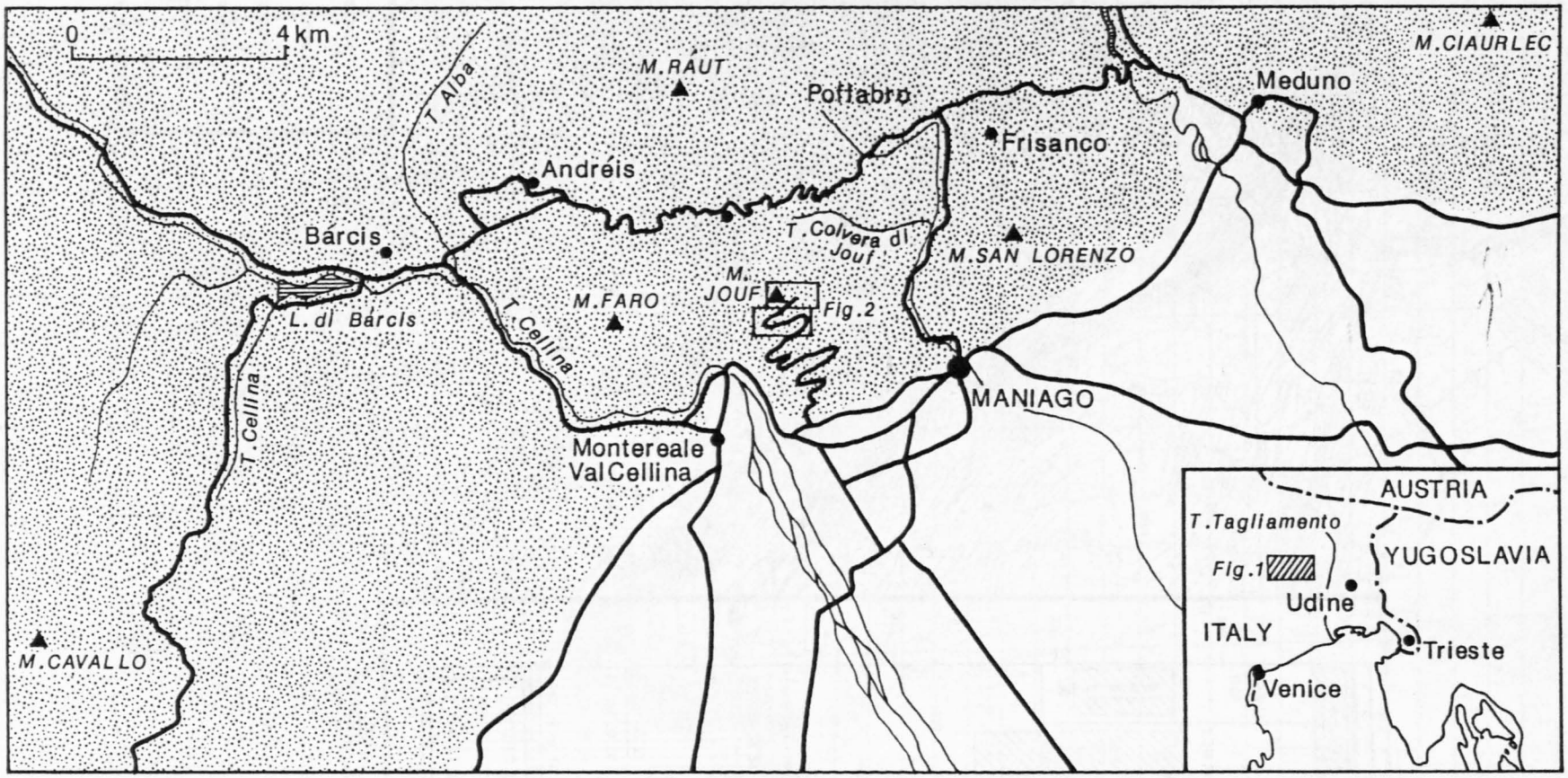

0
4 km
M.RAUT
T.Alba
Pottabro
Andréis
Frisanco
Meduno
M.CIAURLEC
Bárcis
T.Colvera di Jouf
M.SAN LORENZO
M. JOUF
Fig.2
M.FARO
L.di Bárcis
T.Cellina
T.Cellina
MANIAGO
Montereale Valcellina
M.CAVALLO
AUSTRIA
T.Tagliamento
Fig.1
YUGOSLAVIA
Udine
ITALY
Trieste
Venice

Fig 1

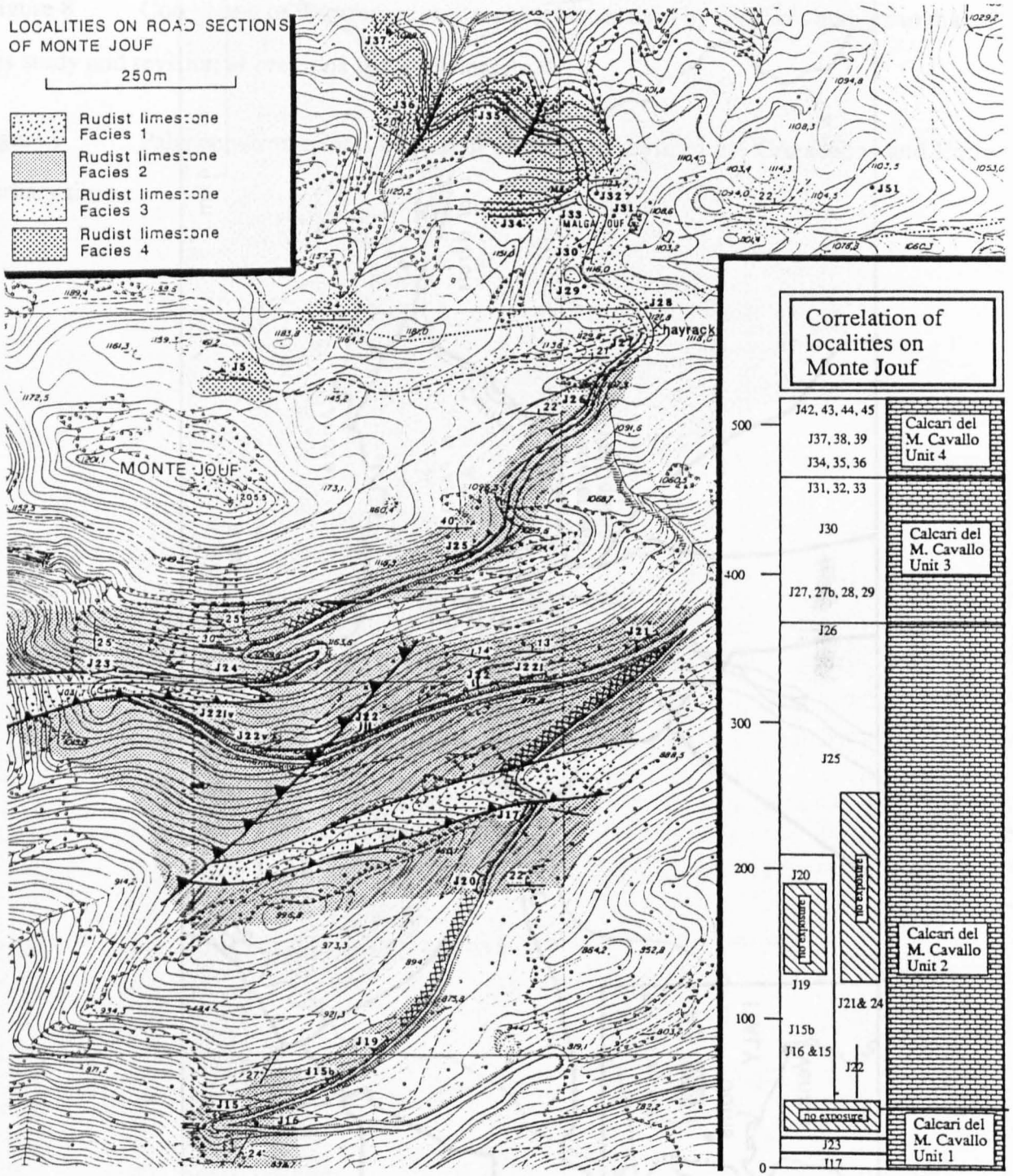

LOCALITIES ON ROAD SECTIONS OF MONTE JOUF
250m
Rudist limestone Facies 1
Rudist limestone Facies 2
Rudist limestone Facies 3
Rudist limestone Facies 4
MONTE JOUF
MALGA JOUF
havrack
Correlation of localities on Monte Jouf
500
400
300
200
100
0
J42, 43, 44, 45
J37, 38, 39
J34, 35, 36
J31, 32, 33
J30
J27, 27b, 28, 29
J26
J25
J20
J19
J15b
J16 &15
J21& 24
J22
J23
J17
no exposure
Calcari del M. Cavallo Unit 4
Calcari del M. Cavallo Unit 3
Calcari del M. Cavallo Unit 2
Calcari del M. Cavallo Unit 1

Figure 3

Adriano Noacco 1989

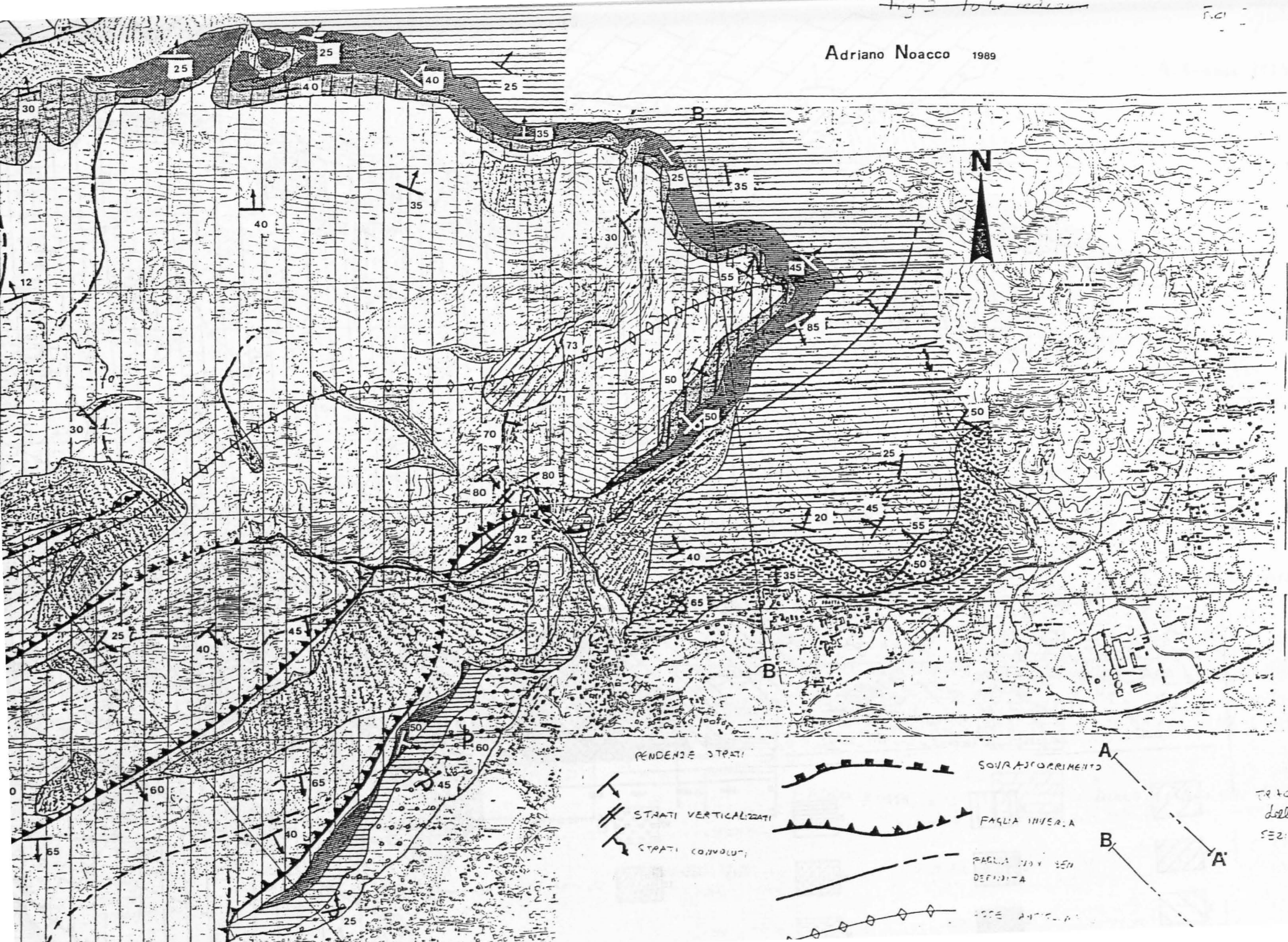
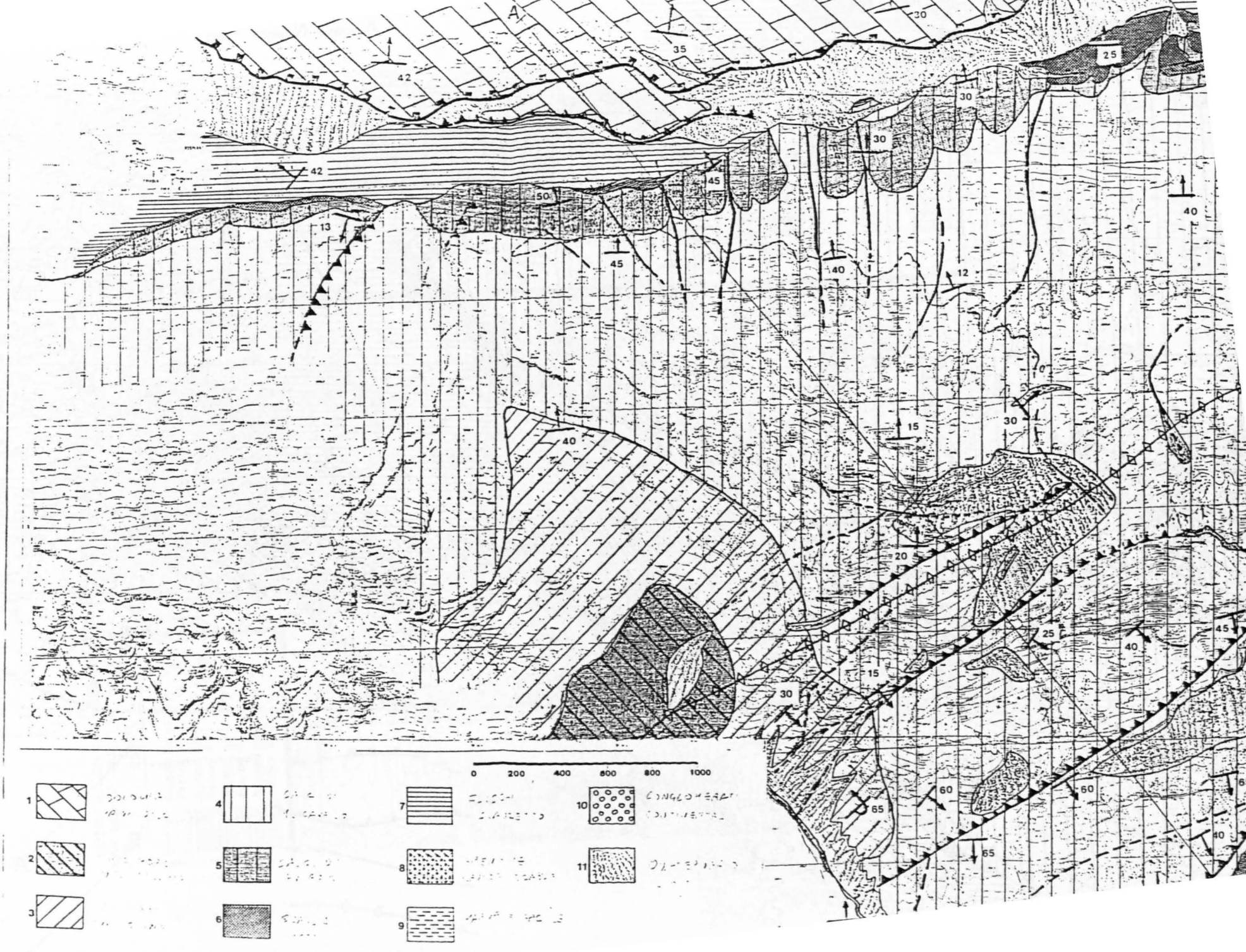
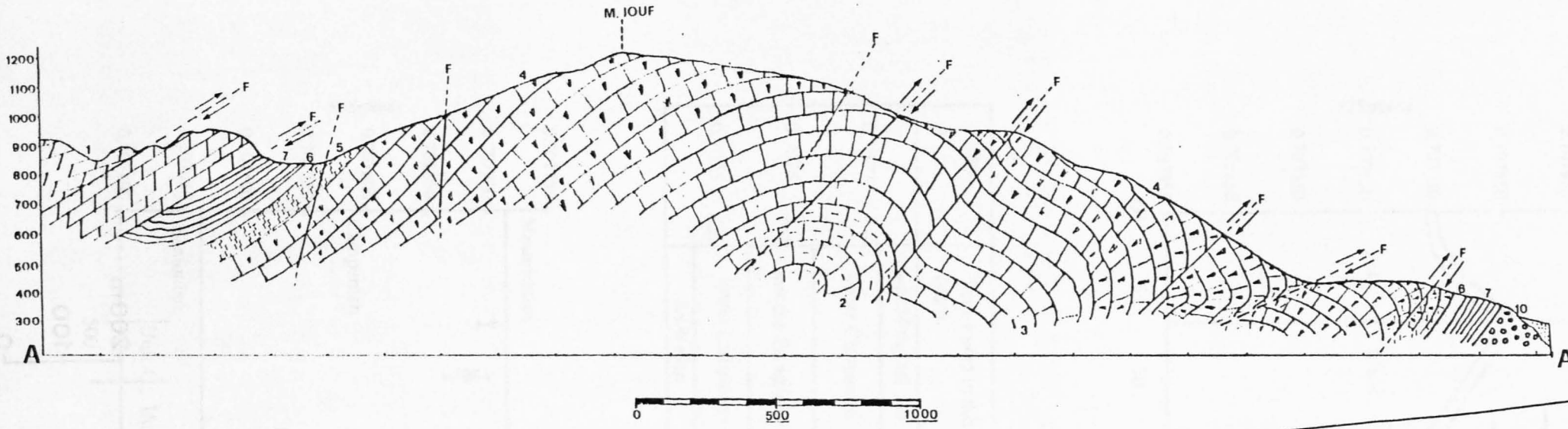


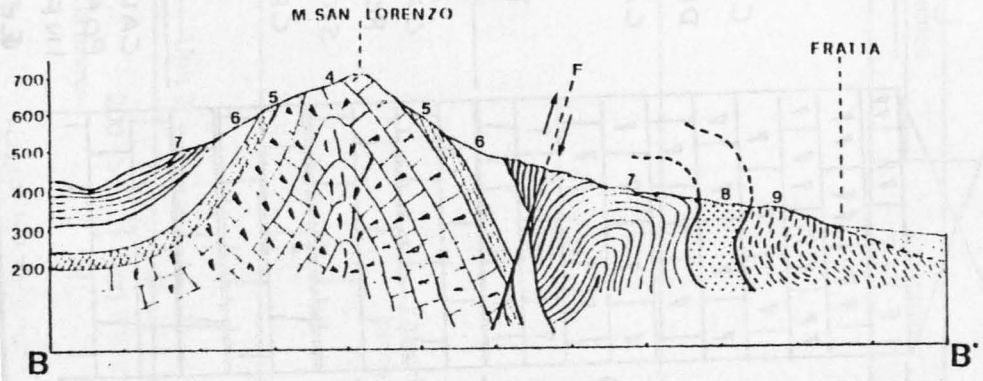
Figure 4 Map a)


A
A'
42
35
30
25
42
30
30
45
50
40
13
45
40
12
0
30
15
40
20
25
40
45
15
30
0
200
400
600
800
1000
1
2
3
4
5
6
7
8
9
10
11
60
65
60
60
65
40

A. Noacco 1989

24 b) Section





Same legend as Section Strat. column

10 CONGLOMERATI CONTINENTALI

9 ARGILLE E MARNE (ELVEZIANO)

8 AREN. GLAUCON. ESABBIE (LANGHIANO)

7 FLYSCH DI CLAUZETTO Eoc. INF.

6 SCAGLIA ROSSA

5 CALCARI DI AMPEZZO

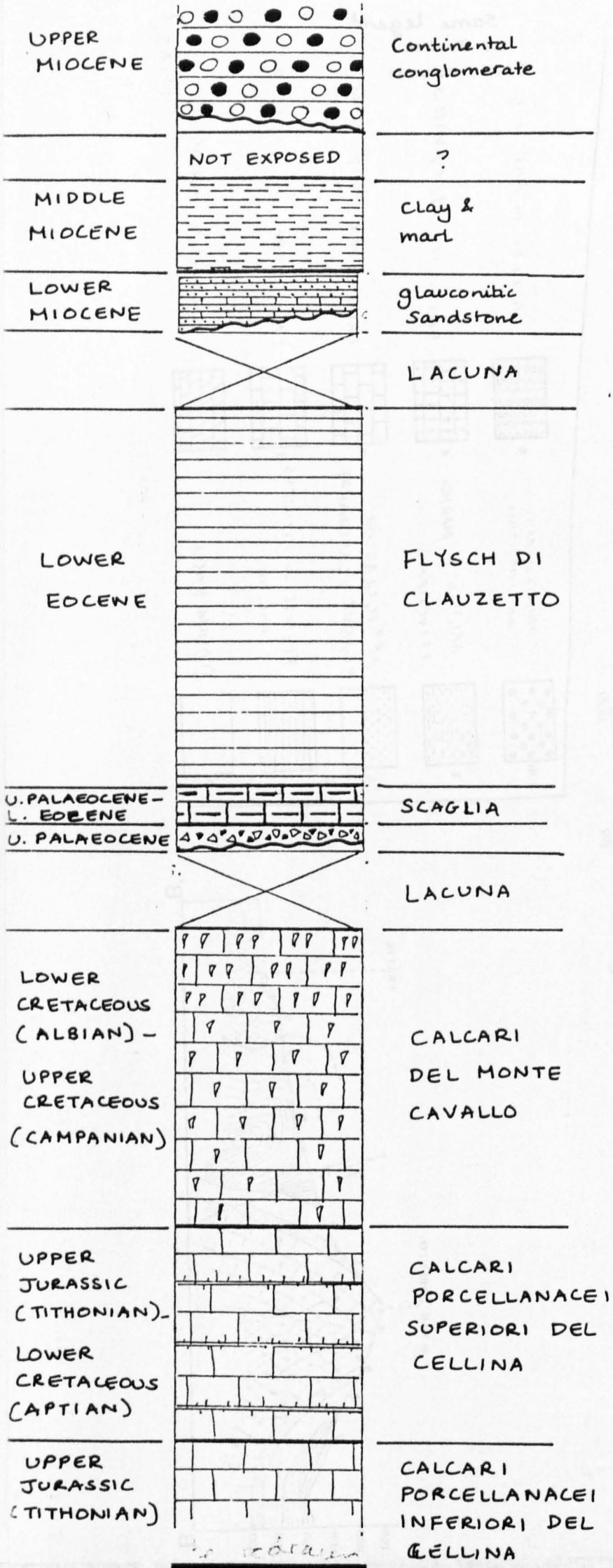
4 CALC. DI M. CAVALLO

3 CALC. PORC. SUP. CENOMANIANO

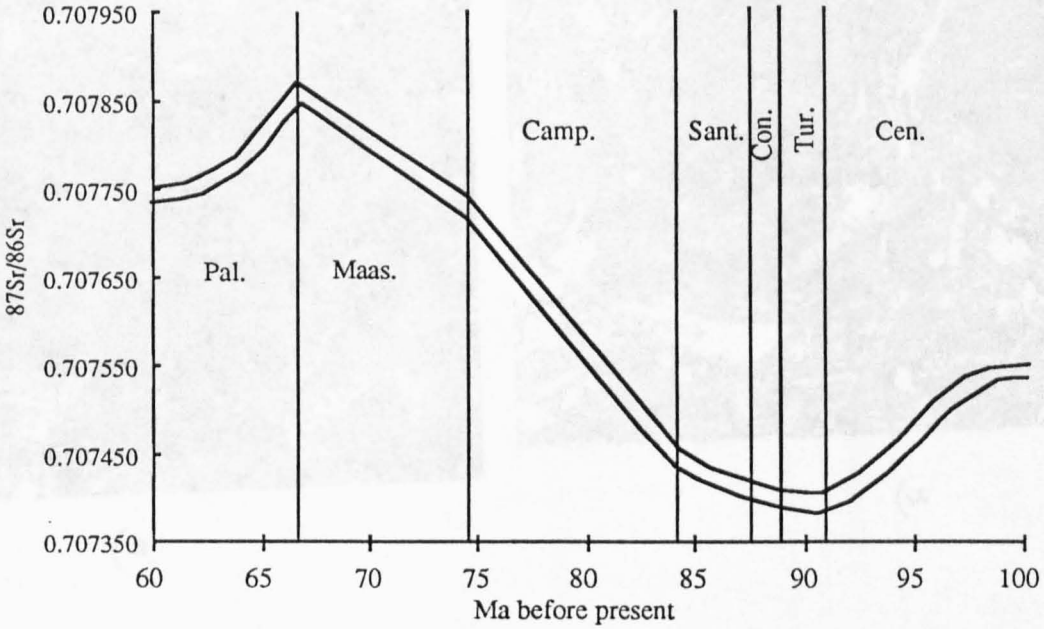
2 CALC. PORC. INF. CENOMANIANO

1 DOLOMIA PRINCIP. TRIAS

4c) Stratigraphic column



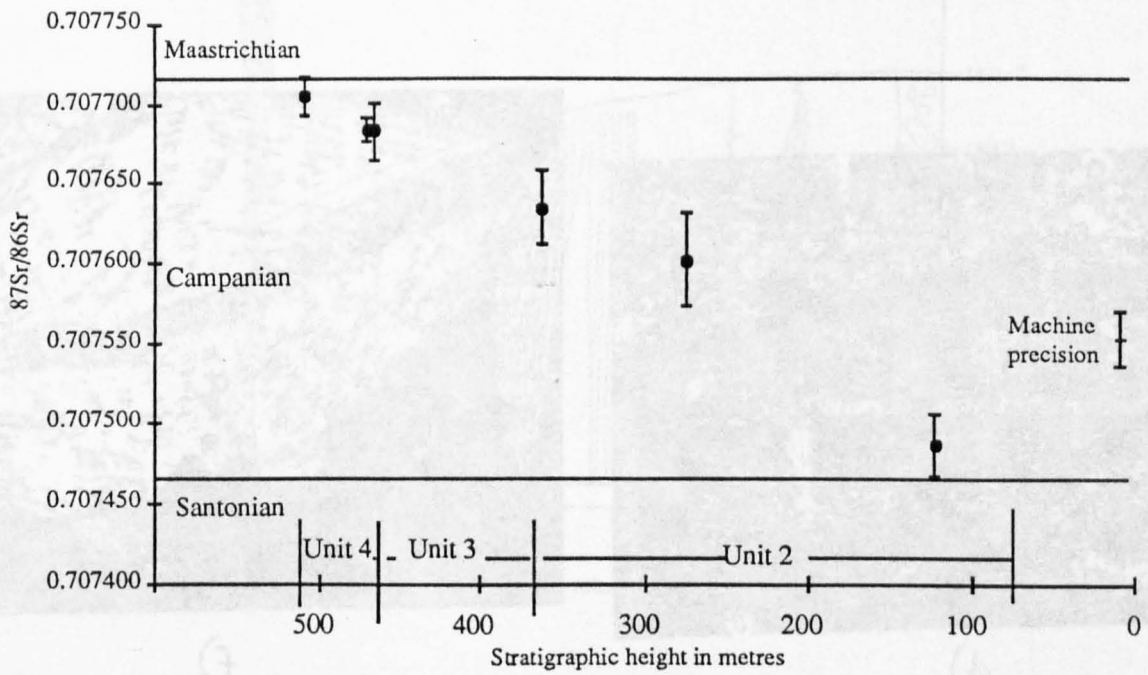
A



B

87/86 Sr	Terms used in this paper	Boreal belemnite stratigraphy	Tethyan planktonic foraminiferal stratigraphy
	lower Maastrichtian	Lower Maastrichtian	lower Maastrichtian
0.7077	upper Campanian	Upper Campanian	Campanian
0.7076	middle Campanian		
0.7075	lower Campanian	Lower Campanian	Santonian ?
	Santonian		

C



a)

e)

b)

c)

d)

f)

Fig 6

intra-
formational
conglomerate
plattenkalk
Algal
laminate
Foram-rich
sediment
Rudist-rich
sediment
grnst
pkst
wkst
Mic
2 meters
supratidal
intertidal
subtidal

Fig 7

<table>
<tr><th>This work
M. Jouf</th><th colspan="2">Cuvillier et al., 1968
Val Cellina</th><th>Saint-Marc, 1963
Val di San Antonio & M. Jouf</th><th colspan="2">Cousin, 1963a
M. Ciaurlec</th></tr>
<tr><td>Calcari di Andreis
Palaeocene</td><td colspan="2">Calcari di Andreis
Upper Palaeocene</td><td>Scaglia Rossa</td><td>Scaglia Rossa
Maas.?</td><td>Flysch ?
U. Pal.</td></tr>
<tr><td>Unit 4
C/M boundary - uppermost Campanian</td><td rowspan="4">Zone of Cuneolina pavonia parva - Dicyclina schlumberger</td><td>Subzone of
Orbitoides ss.
Maas. - Camp.</td><td>Orbitoid and rudist limestone
Maas. - Camp.</td><td colspan="2">Orbitoid limestone
Maas.</td></tr>
<tr><td>Unit 3
uppermost Campanian - middle Campanian</td><td rowspan="2">Santonian - Upper Turonian</td><td>Hippuritid limestone
Campanian - Santonian</td><td colspan="2" rowspan="3">Hippuritid and Caprinid limestone
Senonian
? ?
Radiolitid and Hippuritid limestone
Turonian</td></tr>
<tr><td>Unit 2
middle Campanian - lowermost Campanian</td><td>Radiolitid limestone
("Coniacian - Turonian")</td></tr>
<tr><td>Unit 1
Upper Cenomanian</td><td>Subzone of
Nezzazata simplex
Lower Turonian</td><td>Caprinid limestone
Cenomanian</td><td colspan="2">Caprinid and Radiolitid limestone
Cenomanian</td></tr>
</table>

Fig. 8

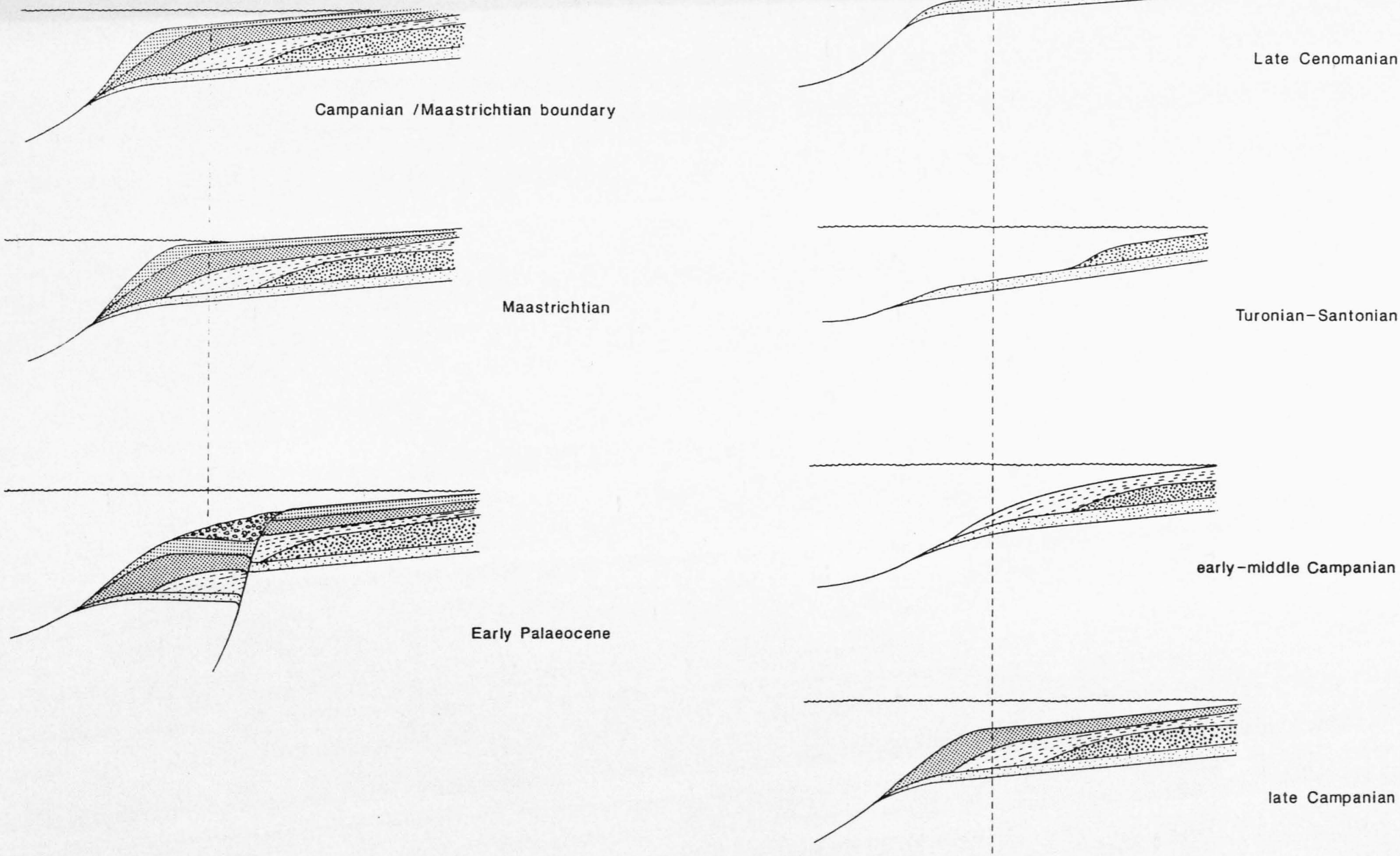

Campanian /Maastrichtian boundary
Maastrichtian
Early Palaeocene
Late Cenomanian
Turonian–Santonian
early–middle Campanian
late Campanian

Fig. 9